Sequential Innovation and Hybrid Seed Pricing:

The Lessons from Canola Industry in Canada

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Abstract

The present study attempts to fill a gap in the literature by exploring the physical and economic forces that influence the dynamic path of hybrid seed pricing for a broad acre crop over time. Of the physical and economic forces influencing the dynamic path of hybrid development, the sequential and cumulative nature of crop development is particularly discussed. Specifically, the canola hybrid seed industry in Canada is studied. This study will have particularly important implications for industries that are considering stronger intellectual property rights inside and outside Canada.

The model presented in Chapter 2 makes a significant contribution to the "product variety" literature. While Chamberlinian models are confined to one representative consumer and location models are not very helpful in analysis of more than two characteristics, the model developed in Chapter 2 incorporates differentiated buyers and multiple characteristics. Schumpeter's *temporary market power* can be derived from new characteristics embodied in old products. Results show that more progressive industries are likely to have a smaller equilibrium number of firms and shorter product cycles, *ceteris paribus*.

Chapter 3 endogenizes rate of yield potential growth as a function of firms' initial investment. Results show that greater investment productivity results in fewer varieties in the market, shorter product cycles, higher prices, higher profit levels, lower optimal investment, and higher consolidation. Also, it is shown that if increased differentiation creates enough space in the market for a new entrant, then entry of a new rival will increase competition and may result in a decrease in the incumbents' profit.

Chapter 4 uses data from Canadian canola industry to empirically test some of the propositions discussed in Chapter 2. Results confirm that as a variety becomes more specific its market share decreases. It is also shown that degree of specificity is a proper measure of adaptability for seed varieties as it provides high explanatory power in the regression models and also can be used to make direct economic interpretation.

Chapter 5 presents a conclusion, policy implications, and potential approaches for future research.

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Chapter 1: Introduction

1.1. Background

Innovation is a dynamic process that very often takes place through embodying new characteristics in existing products. Buyers care about many characteristics when buying a product. While many desirable characteristics are already embodied in products, some are not. Innovators are aware of the fact that buyers have a desire, and therefore a positive willingness to pay, for these characteristics not yet embodied in a product. There is an opportunity for innovators to increase their profit by creating and embodying a new characteristic in products and then offering the products to the market. This provides an incentive to innovate through the addition of new characteristics.

The introduction of new characteristics is a particularly important means of innovation in agricultural input industries. Like final consumers, farm input buyers value the characteristics of the inputs they purchase. New GPS systems for tractors and combines, more fuel-efficient engines and new herbicides are some examples of innovations that offer new characteristics to farm input buyers. Biological innovation is a particularly important mechanism for innovators to respond to farmers' desires for new characteristics. Seed producers, for example, sequentially introduce new varieties of seed that feature new traits, new disease resistance and other characteristics that suit different regions and areas. The existence of thousands of distinct corn seed varieties[1] in the U.S. seed market is evidence of demand for many characteristics.

In the seed industry, the dynamic path of industry development is strongly influenced by the *sequential and cumulative* nature of crop development, as new varieties are built on the result of past selection and breeding efforts (Pardey, *et al.*, 2004). Seed companies sequentially add to the value of existing varieties resulting in new varieties. The result has been an accumulation of knowledge and yield improvement over time, often with farmers paying increasing prices for new varieties of seed. Exploring the incentives and the strategies employed by firms in an industry characterized by sequential and cumulative innovation will provide important insight into the evolution of such industries over time.

[1] A variety must be distinct from other varieties to be registered.

1.2. Importance and Implications of the Research

Understanding the development of a seed industry, which is characterized by sequential and cumulative innovation, and the impact it has had on producers will give important insights into the potential impact of innovation on the seed industry and the wider economy over time. Given the high rates of return to research, and the scope of the potential costs and benefits for producers, economic research could have profound impact on producers and the economic future of the region.

Policies put in place over the next few years will shape the future of the grain industry for many decades to come. A more complete understanding of how an industry, characterized by sequential and cumulative innovation, can develop will inform better policy choices and investment decisions. This study will have particularly important implications for industries that are considering higher levels of investment in developing new production inputs, inside and outside Canada.

1.3. Literature Review: background on the main concepts of the study

While protected seed pricing has received some attention in economic literature, surprisingly little attention has been paid to how these industries dynamically evolve over time. Shi *et al.* (2010) studied the economics of pricing of hybrid corn seed and postulated that under strategic bundling and imperfect competition farmers are likely to be charged higher prices for seed. Perrin and Fulginiti (2002) examine the implications of the durability of crop traits in a monopolist seed producer's pricing behaviour. Goeschl and Swanson (2003) studied the impact of genetic use restriction technologies (GURT) on the appropriability of returns to research and private investments in agricultural R&D. Ambec *et al.* (2008) investigated the incentives for an inbred line seed producer to switch to nondurable hybrid seed. Although these studies, and many other studies in this area, consider different aspects of seed pricing, (e.g. durability of traits, market structure, etc.) none of them explores how an agricultural industry, characterized by sequential and cumulative innovation, evolves over time. Given the sequential and cumulative nature of crop research, it is important to consider the dynamics at play.

This study borrows the concepts of characteristics and differentiation from the works of Hotelling, Chamberlin, and Lancaster. Also, this study's perspective towards innovation is borrowed from works of Schumpeter (1939, 1942) and Moschini and Lapan (1997). For this reason, these studies are reviewed in more depth than other works that are used in the current study. Next few paragraphs review works of Schumpeter (1939, 1942) and Moschini and Lapan (1997), Hotelling (1929), Chamberlin (1933), and Lancaster (1966, 1971, 1990) from the perspective of this study. The literature on sequential and cumulative innovation owes to many scholars, particularly Suzan Scotchmer. This literature is reviewed in this section as well. Chapters 2, 3, and 4 briefly describe other works that are relevant to each chapter of this dissertation.

1.3.1. Schumpeter: Dynamics at Play

Schumpeter (1939, 1942) is perhaps one of the very first to place great emphasis on importance of dynamics in evolution of market economies. In Schumpeterian perspective, innovation is the main pivot of industrial evolution. Schumpeter argues that innovation-originated market power creates temporary above normal profits. He believed that the temporary above normal profits resulting from temporary market power is necessary to "induce" innovation, although this market power is doomed to be competed away as new and existing firms start imitating the monopolist's innovation (Schumpeter, 1939).

Schumpeter (1939), in *Business Cycles*, defines four phases for a business cycle: *prosperity, recession, depression,* and *revival*. Innovation is the ignition of a business cycle. An entrepreneur implements the new innovation and obtains above normal profits. Above normal profits in the industry encourages new and existing firms to adopt the new innovation. Those businesses that are not able to adopt the new, usually cost-reducing, innovation will be forced out of the market. Schumpeter calls this process *creative destruction* because the creativity embodied in the new innovation literally destroys the stock of capital used in older innovations (Schumpeter, 1939).

Business cycles, in Schumpeter's thoughts are irregularly regular (Schumpeter, 1939: 25). That is, there is no doubt that business cycles happen and they will happen in the order suggested by Schumpeter, but history and economic theory cannot help much predict how long a particular cycle or phase will take.

Answering the question who performs innovations, Schumpeter initially suggested that small companies might have a flexibility advantage over large companies (entrepreneurial innovation or Mark I model). For example, it could be more difficult for large companies to deal with bureaucratic structures. In his later works, however, Schumpeter argues that larger companies have a privilege in producing innovations via R&D investments (Mark II model). Schumpeter specifically attributes this privilege to economies of scale and barriers to entry that larger companies create over time (Schumpeter 1947, 1949).

Three elements are always prominent in Schumpeter's ideas: the dynamic outlook he took from Marx, the emphasis on historical specificity he learned in the historical school, and the need for a micro-based approach he borrowed from the Neoclassicals (Fagerberg, 2002).

Throughout his writings, Schumpeter uses the term "neighbourhood of equilibrium". This is not the same as the concept of equilibrium with the neoclassical meaning. In the neighbourhood of equilibrium, the capitalist economy is constantly moving away from an old equilibrium and towards a new equilibrium.

1.3.2. Moschini and Lapan: Drastic vs. Non-drastic Innovation

Arrow (1962) introduced the concept of drastic innovation. Moschini and Lapan (1997) show how to appropriately measure the welfare effects of innovations in agricultural markets. They claim that the welfare effects of an innovation in the agricultural markets depend on whether the innovation is drastic or non-drastic as well as on the existing market structure before the innovation occurs. An innovation is drastic if it's valuable enough to lead to "unconstrained monopoly price of the innovated input" and is non-drastic if "the monopolist's pricing decision is constrained by the threat of competition" (Moschini and Lapan, 1997).

Drastic innovations are very unlikely to occur in crop research. This is in part due to sequential and cumulative nature of crop innovation. In crop development, new varieties are built on the result of past selection and breeding efforts (Pardey, *et al.*, 2004). Also, drastic innovations are very unlikely to occur in crop research because farmers differ in their demand for new varieties and any new variety is unlikely to be superior to existing varieties for all farmers. Non-drastic innovations, on the other hand, are very common in the seed industry.

Figure 1.1 shows this pattern for four canola varieties in Saskatchewan (2008-2012). As shown in Figure 1.1, none of the varieties were able to take over all other varieties and dominate the whole market. The common trend is a hill-shaped adoption curve. Even when a variety is at the top of its adoption hill, a number of other varieties have significant market shares. For example, market share of 5020 decreases as 5440 and 45H28 become adopted. Similarly, 5440 continues its disadoption process when L150 is introduced. The co-existence of more than one variety in the market signifies the non-drastic nature of these varieties.

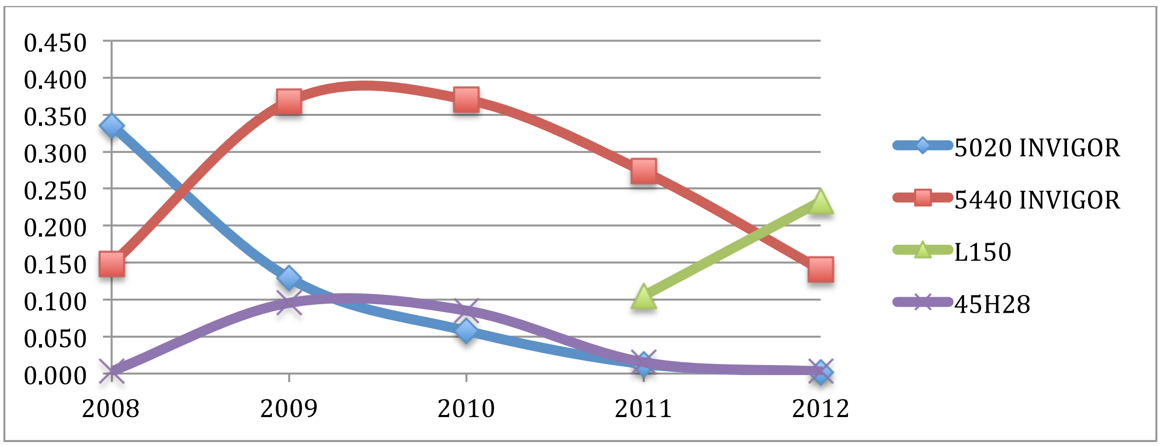


Figure 1. 1. Adoption rate of four Canola Varieties in Saskatchewan (2008-2012).

Source: Saskatchewan Crop Insurance Corporation.

Although he never uses the term "drastic innovation", in his innovation theory, Schumpeter implicitly assumes innovations are drastic. That is, the new innovation destroys the old ones. However, he does consider room for non-drastic innovations in his framework. Schumpeter suggests that a new innovation acts similar to a wave that creates a dynamic cycle in the economy. On the back of each wave, however, innovations of smaller magnitude (i.e. non-drastic innovations) could be performed by the original entrepreneur or imitators (Schumpeter 1939). These smaller non-drastic innovations, which are cumulatively built on the original drastic innovation, compete with the original drastic innovation. As a result, the original entrepreneur can no longer charge a monopoly price and the original drastic innovation turns into a non-drastic innovation.

1.3.3. Scotchmer: "Standing on the Shoulders of Giants"

Suzan Scotchmer did many studies on sequential and cumulative innovation. Many of her studies have been focused on patent policies in a world of sequential and cumulative innovation. In a paper titled "Standing on the Shoulders of Giants: Cumulative Research and the Patent Law" Scotchmer (1991) criticizes the economics literature on patenting for ignoring the cumulative nature of innovation and explores different policy options to provide incentives to innovate when research is of cumulative nature.

Green and Scotchmer 1995 argue that in markets with sequential innovation imitators erode the original innovator's profit. In quest of an effective policy, they argue that in order to ensure a large enough share of the "second-generation" profits, patents should be of longer life when more than one firm is involved in the process of sequential innovation.

O'Donoghue (1998) investigates the patentability requirement when firms engage a series of sequential innovations. He suggests that "a patentability requirement can stimulate R&D investment and increase dynamic efficiency."

Grossman and Helpman (199la, 1991b), Aghion and Howitt (1992), Romer (1986), and Stokey (1995)) study the relationship between investment in sequential innovation and economic growth. This literature also highlights the role of Schumpeterian "creative destruction" in "endogenous-growth". It is worth noting that this literature investigates non-drastic innovations whereas Schumpeterian "creative destruction" relates to drastic innovations (O'Donoghue, 1998). Role of cumulative innovation in technological improvement has also been emphasized by Rosenberg (1982, 1994), Usher (1954), Gilfillan (1935), and Hunter (1949).

This literature is very important for the current study, particularly for Chapter 3. Grossman and Helpman (1991a) argue that "almost every product exists on a *quality ladder*, with variants below, that may already have become obsolete, and others above, that have yet to be discovered." This is similar to the Schumpeterian innovation theory in which older products enjoy the above-normal profit for a limited time and then they are replaced by newer and higher quality products, resulting in product cycles. Grossman and Helpman (1991a) criticize the literature on patent races introduced by Loury (1979), Dasgupta and Stiglitz (1980), and Lee and

Wilde (1980) for having a “one-shot framework [that] fails to capture an essential aspect of quality competition.” Grossman and Helpman (1991a) refer to the works of Segerstrom et al. (1990) and Aghion and Howitt (1990) as “the beginning of a theory of repeated quality innovations.” An important element of these models is “endogenous technical change” (Grossman and Helpman, 1991a). Chapter 3 of this dissertation endogenizes investment in yield potential improvement as a function of future expected profits.

O'Donoghue et al. (1998) introduce the concept of “effective patent life”, which is a function of “patent breadth” and “patent life”. They investigate the role of these two factors in the “pace of technological progress”. They argue that “to fully capture the impact of the cumulative nature of the innovations on the incentive to innovate, it is useful to consider a dynamic model where improvements of the innovation arise randomly.”

Langinier and Moschini (2002) investigate the role of patents as incentives to innovate, for both single and cumulative types of innovation. They also investigate the relationship between patent systems, market structure, and R&D investment. They argue that “by endowing discoverers with property rights over the fruits of their efforts, patents affect the incentive to innovate and are likely to increase the flow of innovations.” They also claim that in a world of cumulative innovations, the occurrence of the original innovation is important for facilitating the next generations of the innovation.

Wright et al. (2007) provide a discussion around the agricultural research funding systems with a focus on the role of various incentives to innovate. In particular, they highlight the role of intellectual property rights.

Gilbert and Newbery (1982) explore the incentives for “preemptive patenting”. They argue that (under the deterministic invention assumption) a R&D market with no imperfections makes the preemtive efforts costless and the persistence of the monopoly “doubly attractive”.

Reinganum (1983) investigates Gilbert and Newbery’s results under the assumption of stochastic invention. She shows that the original innovator is less likely than the “challenger” to patent the innovation. She argues that this is because if the original innovator is successful then he “merely replaces himself”. This means the original innovator has “a lower marginal incentive to invest in R&D than does the challenger”.

1.3.4. Hotelling, Chamberlin, and Lancaster: Differentiation and Characteristics

Another key feature of crop research is the differentiation of crop varieties; dozens, sometimes thousands of distinct crop varieties, grown on spatially distributed, heterogeneous land. Existence of heterogeneous land implies the creation of distinguished varieties with differentiating characteristics. These varieties are usually sequentially introduced to acquire profits by responding to the needs of farmers that are differentiated with respect to their land and other factors.

This study uses the concept of characteristics to describe sequential innovation. The concept of “characteristics” has been discussed in “product variety” literature (Lancaster, 1990). Lancaster (1990) categorizes the monopolistic competition models of analyzing product variety into those tracing back to Chamberlin’s work (Chamberlin, 1933) and those based on Hotelling’s location model (Hotelling, 1929). Location models, including Hotelling’s linear town and Salop’s circle (Salop, 1979), incorporate differentiated buyers but are confined to two characteristics. Chamberlinian models allow for multiple characteristics but are confined to one “representative consumer”.

The “characteristics approach” introduced by Lancaster (1966, 1971) expands the concept of “location” to non-spatial contexts. Models that use the characteristics approach replace locational space by “a virtual space of goods or their characteristics” (Lancaster, 1990). These models are known as “locational analog” models. The current study takes a similar approach as it replaces locational space by a virtual space of seed varieties’ characteristics.

1.4. Canola Industry in Canada

As Canada’s most valuable crop, Canola adds $19.3 billion a year to the economy (Canola Council of Canada, 2015). Every year, 43000 farmers, mostly concentrated in Western Canada, grow canola. As the largest canola producing country in the world, Canada produced 18 million tons of canola in approximately 20 million acres in 2013 (FAO, 2015; Statistics Canada, 2015).

Canadian canola is either exported as seed or processed into oil and meal for human and livestock consumption, respectively, through 13 processing plants across Canada (Canola Council of Canada, 2015).

With introduction of the hybrid varieties and improved Plant Breeders' Rights (PBRs) the role of private sector in the Canadian canola industry has dramatically increased (Brewin and Malla, 2012). From 1998 to 2003 the industry moved from predominantly inbred to mainly hybrid seed varieties. Along with the domination of the hybrid varieties, the role of private sector in canola research has increased. From 1970 to 2000, share of the public sector in canola research decreased from 87 to 30 percent (Brewin and Malla, 2012). Meanwhile, cost of canola seed increased from $6/acre in 1998 to $38.75/acre in 2011 (Saskatchewan Ministry of Agriculture, 1998 and 2011). Today, although most of the canola research is performed by the private sector, the public sector still has an important role in basic research (Brewin and Malla, 2012).

The canola industry owes the increasing private sector involvement to biotechnology and enforcement of Intellectual Property Rights (IPRs) (Brewin and Malla, 2012). The use of biotechnology, particularly herbicide tolerant (HT) and the resulting hybrid technology, and enforcement of IPRs (e.g. Plant Breeders Rights (PBRs) and technical use agreements (TUAs) has helped private firms prevent the re-use of seed by farmers and increase their revenues to approximately $800 million in 2012 (Brewin and Malla, 2012). This, however, has created at least two, perhaps related, sources of concern; one regarding market concentration and the other regarding dramatically increasing prices (Brewin and Malla, 2012; Howard, 2009). As mentioned in the last paragraph, canola seed prices have increased more than 6 times in the 1998-2011 period.

As for market concentration, most of Canadian canola seed is provided by Bayer Crop Science, Monsanto Canada Seeds Inc., Dow Agroscinces Canada Inc., Pioneer Hi-Bred Production Limited, DL Seeds, and Cargill Specialty Oils. Bayer has a significantly higher market share than its rivals (Brewin and Malla, 2012). For example, in 2012, Bayer varieties 5440, 5770, 1145, L120, L130, L150, and L154 dominated 76 percent of Manitoba's canola seed market (see Table 1.1).

Table 1. 1. Market Concentration of Canola Seed Companies in Manitoba, 2012.

Company	Variety	Area(acre)	Market Share (%)
Bayer	5440	585240	22
Bayer	5030	0	0
Bayer	5020	0	0
Bayer	5070	0	0
Bayer	5770	74332	3
Bayer	8440	0	0
Bayer	5108	0	0
Bayer	9590	0	0
Bayer	2573	0	0
Bayer	2663	0	0
Bayer	1145	44866	2
Bayer	L120	28602	1
Bayer	L130	410188	15
Bayer	L150	864541	32
Bayer	L154	27962	1
Bayer	L159	0	0
Bayer	**Total**	**2035730**	**76**
Monsanto	34-55	0	0
Monsanto	34-65	0	0
Monsanto	35-85	0	0
Monsanto	71-45RR	0	0
Monsanto	73-45RR	61530	2
Monsanto	72-55RR	0	0
Monsanto	73-75RR	114278	4
Monsanto	73-65RR	0	0
Monsanto	**Total**	**175808**	**7**
Pioneer	9553	0	0
Pioneer	45H21	0	0
Pioneer	45H29	93194	3
Pioneer	45H28	0	0
Pioneer	45H26	0	0
Pioneer	45H25	0	0
Pioneer	46H75 (ST)	0	0
Pioneer	**Total**	**93194**	**3**
Dow	1012RR	232057	9
Dow	2012CL	107742	4
Dow	NEX 845CL	0	0
Dow	NX4 105 RR	0	0
Dow	**Total**	**339799**	**13**
Other Companies	**Total**	**46014**	**2**

Source: Manitoba Agricultural Services Corporation, Canadian Food Inspection Agency, and author's calculations.

The most popular hybrid seed technologies in Western Canada are Liberty Link and Roundup Ready used by Bayer and Monsanto respectively. Both technologies are GM and provide herbicide tolerance. Clearfield is another non-GM technology currently used by both Pioneer and Dow. It is worth noting that as a result of cross-licensing these companies have been able to use technologies originally developed by their rivals (Howard, 2009). For example, all of the rivals except Bayer, are using Monsanto's Roundup Ready technology. Therefore, the 7 percent market share in Table 1.1 may not truly represent Monsanto's role in the Canola seed industry (Brewin and Malla, 2012).

The seed companies have been responding to farmers' needs by not only focusing on improved yield potential, but also offering other characteristics such as standability, herbicide resistance, pesticide resistance, Blackleg resistance, Clubroot resistance, and Sclerotinia resistance.

1.5. Objectives

Considering the central role of innovation in economic growth, it seems important to study the incentives to innovate. The present study attempts to fill the gap in the literature by exploring the physical and economic forces that influence the dynamic path of hybrid seed pricing for a broad acre crop over time. Of the physical and economic forces influencing the dynamic path of hybrid development, the sequential and cumulative nature of crop development is particularly discussed. This study attempts to answer the following questions: What is the incentive to create new production inputs that embody new characteristics? How are these sequentially introduced inputs priced? What role does sequential innovation play in the seed producers' pricing decisions? How does a seed industry characterized by sequential and cumulative innovation evolve over time? Understanding the role of sequential innovation in the seed producers' behaviour and the seed industry's evolution path has important policy implications for innovators and policy-makers.

1.6. Organization of the Study

This dissertation consists of three main papers presented as Chapters 2, 3, and 4, as well as an introduction (Chapter 1) and Summary and Conclusions (Chapter 5).

Chapter 2 introduces a new theoretical model that explains the incentives to create new characteristics for new production inputs. This model incorporates competition among *n* differentiated production inputs each embodying new characteristics. In this chapter, some properties of the model are shown in form of propositions and algebraic proofs. Particularly, effect of rate of innovation on equilibrium conditions is explored.

This model makes a significant contribution to the “product variety” literature. While Chamberlinian models are confined to one representative consumer and location models are not very helpful in analysis of more than two characteristics, the model developed in Chapter 2 incorporates differentiated buyers and multiple characteristics. What distinguishes this model from similar models is the focus on farm input characteristics rather than characteristics in consumer products as well as incorporating sequential innovation via new seed characteristics.

Chapter 3 builds on the results derived from the theoretical model to consider other aspects of sequential innovation. In chapter 3, numerical simulations are performed to further investigate the validity of the propositions presented in Chapter 2. This chapter seeks to provide some insights into dynamic aspects of the model, such as product cycles.

The most important contribution of this chapter to the literature is the insights that it provides into the effect of rate of innovation, degree of specificity of seed varieties, and cost structure on length of product cycles, number of equilibrium varieties, and other equilibrium conditions. It is found, for example, that a higher rate of innovation results in fewer equilibrium products that are priced higher.

Chapter 4 uses data from Canadian canola industry to empirically test some of the propositions discussed in chapter 2. For this purpose, an “adoption model” is estimated. The adoption model is modified to incorporate the effect of yield potential and degree of specificity of seed varieties rather than their average and variance yield. This chapter makes a significant contribution to the adoption literature by explicitly considering and successfully incorporating the adaptability of varieties via a more tangible measure, degree of specificity, rather than yield variance. Also, this study uses a new econometric approach for estimating adoption models. The adoption model is estimated as a fixed effect panel regression rather than a simple Ordinary Least Squares.

At the end of each chapter policy implications of the findings are discussed. Also, technical limitations and approaches for future studies are discussed at the end of each chapter. Chapter 5 provides a conclusion of the findings of this dissertation.

Chapter 2: Theoretical Model

2.1. Introduction

Innovation often takes place in a sequential manner (Green and Scotchmer, 1995). Particularly, the process of adding new characteristics to products is likely to be sequential. Plant breeders typically use existing elite varieties in their breeding programs to create new varieties with new traits. As discussed by Schumpeter (1939), these sequentially introduced innovations are built on the back of a bigger wave called the original innovation. The original innovation, and the innovations of smaller magnitude built upon the original innovation, are doomed to fade by entry competition, creating business cycles (Schumpeter, 1939). This is particularly evident in the seed markets, where the old varieties are eventually replaced with the new ones.

This study fills a gap in the literature by developing a theoretical model that lays out a process of adding new characteristics to agricultural production inputs, with the purpose of understanding the incentives for sequential innovation via the addition of new characteristics. As elaborated in the body of the chapter, this study derives the equilibrium conditions for n varieties of seed sequentially introduced in n time periods, each of which is differentiated from other varieties with respect to one characteristic. By allowing multi-brand competition, the model overcomes the "immediate neighbours" problem[2], which is common in location models. The model also allows differentiated input buyers so that it is not confined to only one "representative consumer" as in Chamberlinian models. Although the model may have similarities to monopolistic competition models of analyzing product variety (i.e. location, Chamberlinian and hybrid models), it has a different perspective in that it uses the concept of "characteristics" introduced by Lancaster (1966) to explain competition among n differentiated production inputs.

The flexibility of the model in terms of the number of production inputs in the market, potential quality improvements, and the addition of new characteristics leads to interesting and intuitive findings. It is shown that the rate of yield potential improvement and the degree of specificity (the inverse of adaptability) of seed varieties are important determinants of their prices and market shares. Farm input buyers experience unbounded gains from variety. Buyers' gains from variety increase as inputs become more specific. Although this chapter only briefly

[2] The problem refers to firms only competing directly with their immediate neighbors.

explores Schumpeterian innovation cycles, the model provides the basis to study this concept through numerical simulations.

Next is a review of the "product differentiation" literature, and a comparison of the model introduced in this study with existing monopolistic competition models of analyzing product variety. Later, a conceptual framework for incentives to innovate through creation of new characteristics is presented. The theoretical model follows, with some properties of the model presented through propositions and algebraic proofs to provide a better understanding of the behavioral implications. Last, a conclusion and the technical limitations of the study are presented.

2.2. Characteristics in Literature

This study seeks to explore the incentives for sequential innovation via the creation of new characteristics for production inputs. In addition, this study attempts to provide a basis for an analysis of Schumpeterian innovation-induced cycles. For this purpose, this study requires a model that allows for: 1) Differentiated input buyers; 2) Multiple characteristics; and 3) Sequential entry. The next few paragraphs summarize the monopolistic competition models of analyzing product variety that incorporate one or more of these three elements.

Literature on the introduction of new farm input characteristics is sparse. The concept of "characteristics", however, has been discussed in "product variety" literature (Lancaster, 1990). Lancaster (1990) categorizes the monopolistic competition models of analyzing product variety into those tracing back to Chamberlin's work (Chamberlin, 1933) and those based on Hotelling's location model (Hotelling, 1929). Although incorporating differentiated buyers, traditional location models are not very helpful in the analysis of more than two characteristics. Eaton and Lipsey (1976) show the "non-uniqueness" of equilibrium in a two-dimensional (Loschian) location model. Salop (1979) solves the non-existence of equilibrium problem by locating firms on a circle, which has no "end-points." Nevertheless, Salop's circle model faces the "immediate neighbours" problem with more than three firms in the market.

The "characteristics approach" introduced by Lancaster (1966, 1971) expands the concept of "location" to non-spatial contexts. Models that use the characteristics approach replace locational space by “a virtual space of goods or their characteristics” (Lancaster, 1990). These models are known as “locational analog” models.

Lancaster (1990) argues that the dimension of the product space affects the structure of the market equilibrium and optimum variety in locational analog models. He points out that:

> “…the two-characteristic single-dimension model possesses special features that one cannot generalize to higher dimensions. …As the number of relevant characteristics increases the configurations become very complex, with no locational models to draw upon.” (Lancaster, 1990).

This quote highlights the fact that even in more advanced location models, such as Lancaster’s locational analog model (Lancaster, 1979) and Salop’s circle model (Salop, 1979), dealing with multiple characteristics is still an issue. More importantly, location models do not deal with entry very well as they run into the “immediate neighbours” problem with more than two products (or more than three in Salop’s model) in the market. Therefore, use of location models for the purpose of this study may be difficult.

Chamberlinian models, on the other hand, are based on the assumption of one representative consumer purchasing all available brands. Neo-Chamberlinian models, such as that of Dixit and Stiglitz (1977), have this assumption in common with their ancestry. Although the representative consumer assumption allows for multi-brand competition, and thereby multiple characteristics, it also means that buyers are not differentiated in these models. This assumption is inappropriate for agricultural input industries where farmers are differentiated with respect to land, management and other characteristics. Chamberlinian models are not applied to the current study.

Perloff and Salop (1985) were perhaps first to explicitly acknowledge the necessity of combining features of both Chamberlinian and location models in order to allow for differentiated products, differentiated consumers and multi-brand competition. A few other studies (such as those of Anderson and de Palma, 1992a, 1992b; Sattinger, 1984; Besanko et al., 1990; Deneckere and Rothschild, 1992; Irmen and Thisse, 1998) have developed models that combine features of both location and Chamberlinian models. Carlton and Perloff (2005, p. 230) call these hybrid models. Hybrid models start with consumer valuations of all (possible) brands (Perloff and Salop, 1985). Then, demand for each brand is obtained by calculating the proportion of consumers that give the highest valuation to that brand. Equilibrium conditions (e.g. prices and market shares) are then found by substituting the demand for each brand in the firms' profit functions and solving the profit-maximization problem for firms. Two facts are evident in the existing hybrid models. First, although these models incorporate multiple characteristics, they only focus on characteristics embodied in final consumer products. The current study, however, is interested in characteristics embodied in production inputs. Second, to the best of our knowledge, none of the existing hybrid models incorporates sequential entry and/or sequential innovation.

To summarize, in order to understand the changes in market structure and equilibrium conditions in a seed industry over time, it seems necessary to develop a model that focuses on the incentive to create new characteristics for new production inputs in a sequential manner. Specially because non of the existing location, Chamberlinian and hybrid models incorporate sequential entry of production inputs that are differentiated with respect to more than two characteristics and differentiated buyers. As Benkard (2004) claims, "Models of entry for differentiated products are not yet well understood for even just a two-dimensional space."

This chapter develops a theoretical model that focuses on the incentive to create new characteristics for new production inputs. The locational side of the model is locational analog as it treats "location" in a non-spatial context. Nevertheless, similar to Chamberlinian models, competition in this model is non-localized. That is, the model allows every seed variety to compete with every other seed variety.

The model developed in this study is a production-side hybrid model as opposed to the existing consumption-side hybrid models. Chamberlinian and Hotelling-type models (and their descending branches, including hybrid models) have the final consumers of the products on the demand side of the model. In these models, demand for goods is obtained from consumer valuations of various brands. In the current study, however, the demand side of the model consists of demand for a production input, namely seed. Relying on the Neoclassical assumptions, demand functions for various varieties of seed are obtained from a producers' surplus maximization process. This maximization problem translates the demand for *n* differentiated varieties into demand for one commodity, land, and then uses the land constraint to find the land allocated to each variety and thereby find the demand for each variety. The model overcomes the complexity of dimensionality of characteristics space by use of this simple maximization problem on the demand side.

The next section presents the conceptual framework for incentives to create new seed characteristics. This conceptual framework, outlined for a two-input case, provides the basis for the theoretical model presented later.

2.3. Conceptual Framework

Assume two varieties of canola seed can be planted in two parcels of land: a drought-resistant and a herbicide-tolerant variety. The two varieties, however, are not equally suitable for either parcel of land. In parcel 1, the herbicide-tolerant variety yields more than the drought-resistant variety. Panel *i* of Figure 2.1 shows the position of each variety on a two-dimensional characteristics space and the isoprofit curves associated with each variety.

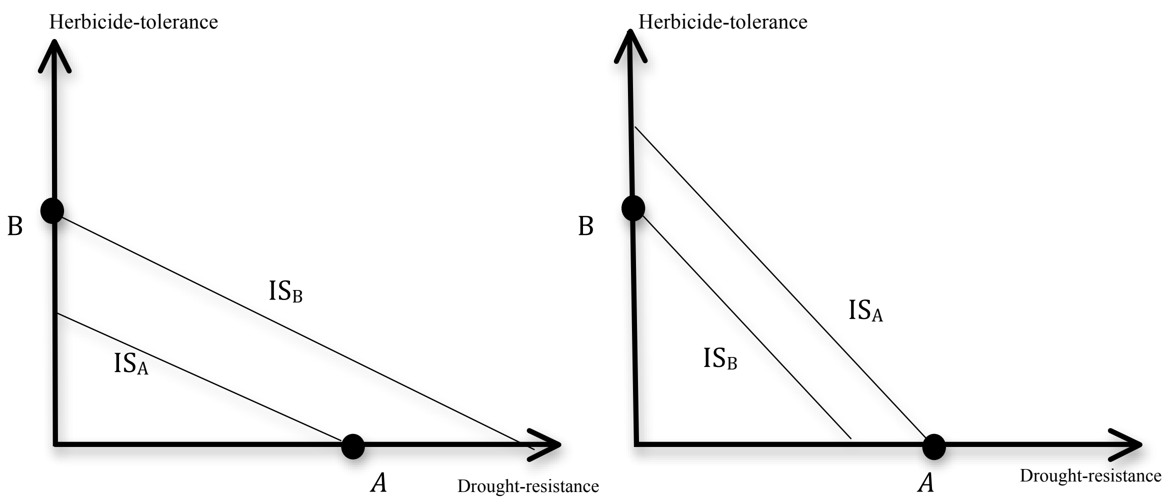
Horizontal and vertical axes measure drought-tolerance and herbicide-tolerance characteristics, respectively. It is assumed that the relationship between varieties of seed and their characteristics is nonlinear in the sense that quantity of the characteristics embodied in a seed variety does not increase as the amount of seed increases. For example, a variety either has the herbicide-tolerance characteristics or not; the amount of herbicide-tolerance characteristic does not increase when more seed is used. It is also assumed that characteristics in varieties of seed are "nonadditive." This is because varieties of seed are "noncombinable" in the sense that two varieties of seed cannot be used simultaneously.[3]

Variety *A* embodies only the drought-resistance characteristic, while variety *B* embodies only the herbicide-tolerance characteristic. This is why variety *A* is located on the horizontal axis and variety *B* is located on the vertical axis. Any variety that is not located on either vertical or horizontal axis contains a bundle of both characteristics. The issue of trait bundling is discussed in Appendix 2.B.

[3] For more information on this issue, please see Lancaster (1979, page 22).

Isoprofit curves associated with varieties *A* and *B* are shown by IS_A and IS_B, respectively. For simplicity, it is assumed that isoprofit curves are linear. Since both varieties are located on the axes, curvature of the isoprofit curve does not affect the analysis.

In parcel 1, variety *B*, the herbicide-tolerant variety, corresponds to a higher isoprofit curve, IS_B, because it performs better on this particular parcel of land. Thus, the farmer who owns parcel 1 will use variety *B* if *A* and *B* are both available and priced equally.



Panel i-Parcel 1 (well-suited for variety B) *Panel ii-Parcel 2 (well-suited for variety A)*

Figure 2. 1 Illustration of Ideal Variety for Two Parcels of Land in a Two-Dimensional Characteristics Space.

Source: Adapted from Lancaster (1979).

Now assume variety *B* is not yet present in the market. When variety *B* does not exist, variety *A* has to be used in parcel 1, which corresponds to a lower isoprofit curve, IS_A. There may be many parcels of land in a region that would move to a higher isoprofit curve if variety *B* were available. That is, although farmers need the herbicide-tolerance characteristic, they cannot reveal their preferences for this characteristic until the herbicide-tolerant variety is introduced to the market. This provides an incentive for innovators to create the herbicide-tolerance characteristic, embody it in a variety (say variety *B*) and offer it to the market. Therefore, the seed producers' incentive for the innovation is earning a higher level of profit by offering a well-suited variety to a group of seed buyers. Seed buyers, on the other hand, purchase the new variety, or more specifically the new characteristic embodied in the new variety, in their quest to find a well-suited variety that accommodates higher profit levels.

Panel *ii* of Figure 2.1 depicts the isoprofit curves for a parcel of land that is well-suited for variety *A* compared to variety *B*. For instance, parcel 2 is more prone to drought and has less weeds than parcel 1. In parcel 2, variety *A*, the drought-resistant variety, corresponds to a higher isoprofit curve, IS_A, because it performs better in this particular parcel of land. Thus, the farmer who owns parcel 2 will use variety *A* if *A* and *B* are both available and priced equally. However, if variety *A* does not exist, variety *B* has to be used in parcel 2. This corresponds to a lower isoprofit curve, IS_B. This provides an incentive for innovators to create the drought-resistance characteristic, embody it in variety *A* and offer it to the market.

In his locational analog model, Lancaster (1979) looks at this issue from a slightly different perspective. In Lancaster's model, each consumer has a "compensating function" that represents how distance from the consumer's "ideal good" can be compensated by increased consumption of a second-best good. In other words, "distance" from the ideal good decreases the consumer's utility and that decrease is compensated by an increased consumption of another good. In the above example, it is assumed that farmers have to commit to the prescribed seeding rate so they cannot compensate the distance from the "ideal variety" by increasing the seeding rate of the second-best variety. In the current model, buyers earn lower producer surplus from a non-ideal variety until the ideal variety is introduced to the market.

With this introduction, it is now postulated that there are *n* characteristics that buyers have a positive willingness to pay for, whether or not those characteristics are yet introduced to the market. Each of these *n* characteristics is latent until an innovator reveals it. When a firm introduces a new product, it incorporates a new characteristic that differentiates it from competitor products. For example, if there are no insect-resistant varieties, a seed producer can differentiate its variety from existing varieties by making an insect-resistant variety. Only once this variety is introduced is the insect-resistant characteristic present. Now a group of seed buyers can reveal their preferences for this characteristic. Thus, the innovators' incentive for creating a new characteristic is capturing a dimension of the *n*-dimensional characteristics space that has not been taken previously by other products. By successfully doing, so the innovator creates the opportunity to capture a portion of the market and potentially increase his or her profit.

The next section presents the theoretical model developed for analyzing the competition among *n* new characteristics embodied in *n* new production inputs.

2.4. Theoretical Model

2.4.1. Assumptions

This section presents the critical assumptions of the theoretical model. In order to focus on multiple characteristics, differentiated inputs and seed buyers, sequential innovation, and competition among differentiated products the model has made a few simplifying assumptions. While some of these assumptions are traditional in the literature, some are specific to this study and the model developed to study a seed industry. The technical limitations that these assumptions may create are discussed at the end of this chapter.

Farmers: It is assumed that there are $f \in \{1, \cdots, F\}$ canola farmers in a region. Each farmer owns at least one parcel of land. The farming activity is assumed to be perfectly competitive. Farmers maximize their surplus from their crop. For simplicity, it will later be assumed that output price is equal to 1.

Land: Each parcel of land $j \in \{1, \dots, m\}$ is characterized by a row vector of *n* characteristics $\theta_j = \{\theta_{1j}, \theta_{2j}, \dots, \theta_{nj}\}$, which differentiates each parcel from other parcels. Characteristics θ_1 to θ_n are determined by land characteristics (e.g. soil texture, soil nutrients and soil moisture, weather, disease pressure), farmers' management skills, machinery in use, past land management (e.g. previous crop pattern, previous diseases), and other factors unique to each parcel of land. For simplicity, it will later be assumed that total available land is equal to 1. Within the landscape, land characteristics are assumed to be i.i.d. and random with uniform distributions scaled to [0,1] lower and upper bounds.

Seed varieties: It is assumed that there are $i \in \{1, \dots, n\}$ crop varieties that are sequentially introduced into the market. Each variety consists of *n* latent characteristics. For simplicity it is assumed that each variety offers only one characteristic. Therefore, each variety is differentiated from other varieties with respect to a unique characteristic in the vector of seed characteristics $L_i = \{L_{1i}, L_{2i}, \dots, L_{ni}\}$.[4] This vector determines whether or not a variety embodies a specific characteristic. Therefore, each element of this vector can only take the values zero and one. If a variety embodies a characteristic, the corresponding element in the L_i vector is one and otherwise zero. Since the elements of the vector of seed characteristics can only take one value, one or zero, seed characteristics do not have a distribution.

Interaction of Seed and Land: For tractability, it is assumed that each variety characteristic linearly interacts with only one corresponding land characteristic to determine yield (i.e. a one-to-one relationship between seed and land characteristics). The model assumes that characteristics embodied in a production input determine the value of that input; it is the traits embodied in a seed variety that determine farmers' willingness to pay for that variety.

The Seed Industry: Varieties of seed are introduced by $i \in \{1, \dots, n\}$ seed producers. Market structure of the seed industry is assumed to be monopolistic competition. Therefore, each seed producer faces a downward sloping demand curve. This is consistent with the differentiated nature of the seed varieties. It is also assumed that all firms have the same cost structure with positive sunk fixed cost equal to *FC* and zero marginal cost.

Although in reality the new varieties are usually introduced by existing firms, for simplicity this study assumes that varieties are separately owned. Another underlying assumption is that firms have no foresight. That is to say the model presented in this study is not a dynamic Industrial Organization model. Instead, it is assumed that there is no price stickiness, so firms can choose a new profit-maximizing price in each period when a new product is added to the market.

[4] For example, variety 1 is drought-resistant, the second variety is not drought-resistant but is disease-resistant, and the third variety is neither drought-resistant nor disease-resistant but is herbicide-tolerant.
With simple modifications the model works for trait bundling as well. The issue of trait bundling is discussed in Appendix B.

2.4.2. Demand for seed

In this "production side hybrid model", the demand for characteristics (embodied in seed varieties) originates from the surplus-maximizing input purchase decisions of firms endowed with heterogeneous fixed factors of production. Specifically, parcels of land are differentiated with respect to land characteristics.

Each variety has a yield potential of $\hat{y}_i$. The yield potential $\hat{y}_i$ determines the highest yield level that a variety could potentially reach. The response of varieties to a change in land characteristics incorporated in the analysis through the vector $\mu_i = \{\mu_{1i}, \mu_{2i}, \ldots, \mu_{ni}\}$. This vector represents the response of the yield of variety i as a result of one unit change in the corresponding land characteristics.

In short, in order to determine the yield of variety i in parcel j one needs to know the yield potential of variety i ($\hat{y}_i$), land characteristics of parcel j (θ_j), the characteristics that variety i embodies (L_i), and how variety i responds to the land characteristics (μ_i).

The one-to-one interaction of land and seed characteristics determines the yield level of each variety in each parcel of land. Thus, yield of variety i at parcel j is determined by the interaction of characteristics of variety i and characteristics of parcel j. This linear [5] one-to-one interaction could be shown in matrix form:

$$[\hat{y}_i]_{m\times n} - [\theta_{ji}]_{m\times n}\times[\mu_{ii}]_{n\times n}\times[L_{ii}]_{n\times n} = [Y_{ji}]_{m\times n}$$

or

$$\begin{bmatrix} \hat{y}_1 & \cdots & \hat{y}_n \\ \vdots & \ddots & \vdots \\ \hat{y}_1 & \cdots & \hat{y}_n \end{bmatrix}_{m\times n} - \begin{bmatrix} \theta_{11} & \cdots & \theta_{n1} \\ \vdots & \ddots & \vdots \\ \theta_{1m} & \cdots & \theta_{nm} \end{bmatrix}_{m\times n} \times \begin{bmatrix} \mu_{11} & \cdots & \mu_{1n} \\ \vdots & \ddots & \vdots \\ \mu_{n1} & \cdots & \mu_{nn} \end{bmatrix}_{n\times n} \times \begin{bmatrix} L_{11} & \cdots & L_{1n} \\ \vdots & \ddots & \vdots \\ L_{n1} & \cdots & L_{nn} \end{bmatrix}_{n\times n} = \begin{bmatrix} Y_{11} & \cdots & Y_{1n} \\ \vdots & \ddots & \vdots \\ Y_{m1} & \cdots & Y_{mn} \end{bmatrix}_{m\times n}$$

where $[\hat{y}_i]_{m\times n}$ represents the yield potential levels of varieties $i = 1, \ldots, n$, $[\theta_{ji}]_{m\times n}$ the levels of n independent land characteristics in $j=1,\ldots,m$ parcels of land, $[\mu_{ii}]_{n\times n}$ the response of the yield

[5] For simplicity, it is assumed that the relationship between yield, seed characteristics and land characteristics is linear. This is merely to show that observed yield levels could be traced back to observed and unobserved seed and land characteristics.

of variety i as a result of one unit change in the corresponding land characteristics, $[L_{ii}]_{n\times n}$ the seed characteristics in varieties $i \in \{1, \dots, n\}$, and $[Y_{ji}]_{m\times n}$ the yield levels of varieties $i \in \{1, \dots, n\}$, at parcels $j \in \{1, \dots, m\}$. For example, yield level of variety 1 in parcel 1 is found as follows:

$$Y_{11} = \hat{y}_1 - (\theta_{11}\mu_{11}L_{11} + \theta_{21}\mu_{21}L_{21} + \theta_{31}\mu_{31}L_{31} + \cdots + \theta_{n1}\mu_{n1}L_{n1})$$

As mentioned before, it is assumed that each variety offers only one characteristic. Therefore, the off-diagonal elements in $[\mu_{ii}]_{n\times n}$ and $[L_{ii}]_{n\times n}$ matrices become zeros and μ_{ii} and L_{ii} can be simplified to μ_i and L_i, respectively. That is, L_i represents characteristic *i*, which is only offered by variety *i*, and μ_i represents the response of the yield of variety *i* as a result of a unit change in the land characteristic that corresponds to the seed characteristic *i*.

Since land characteristics are i.i.d. uniform variables ($\theta_j \sim u(0,1)$) and seed characteristics do not have a distribution, the resulting yield levels are i.i.d uniform variables with the following distribution:

$$Y_i \sim u(\hat{y}_i - \mu_i, \hat{y}_i)$$

That is, yield of variety i is uniformly distributed between $\hat{y}_i - \mu_i$ and $\hat{y}_i$ over the range of the parcels of land.

Now it can be explained why the land characteristics are chosen to be independently distributed. Given the one-to-one relationship between land and seed characteristics, the independence of land characteristics' distributions implies new varieties have independent yield distributions. This independency is necessary as this study is only focusing on new products with characteristics that are completely new. Note that if the new characteristics are not completely new, then the distributions of the yield levels will be correlated (i.e. not independent). [6]

[6] Although the issue of substitutability is not discussed in this study, it is worth noting that as the yield levels of two varieties become more positively correlated, the degree of substitutability of the two varieties increases. Similarly, as yield levels of two varieties become more negatively correlated, substitutability decreases. Therefore, substitutability could be incorporated in the model through distribution of land characteristics.

The following numerical example shows how the interaction between land and seed characteristics determines yield of each variety. Assume there are 10 parcels of land characterized by θ_1, θ_2, and θ_3. θ_1, θ_2, and θ_3 are random and independent land characteristics. The following matrix shows these randomly drawn land characteristics for parcels $j = 1, \cdots, 10$.

$$\begin{array}{c} \\ 1 \\ 2 \\ 3 \\ 4 \\ 5 \\ 6 \\ 7 \\ 8 \\ 9 \\ 10 \end{array} \begin{array}{c} \begin{array}{ccc} \theta_1 & \theta_2 & \theta_3 \end{array} \\ \begin{bmatrix} 0.23 & 0.45 & 0.39 \\ 0.29 & 0.04 & 0.19 \\ 0.25 & 0.73 & 0.33 \\ 0.48 & 0.41 & 0.45 \\ 0.34 & 0.90 & 0.23 \\ 0.96 & 0.09 & 0.53 \\ 0.86 & 0.96 & 0.89 \\ 0.52 & 0.85 & 0.85 \\ 0.71 & 0.22 & 0.98 \\ 0.21 & 0.19 & 0.50 \end{bmatrix} \end{array}$$

Assume there are three varieties of seed available. Variety *A* offers only characteristic L_1, *B* offers only L_2, and *C* offers only L_3. Thus, matrix of variety characteristics can be formulated as follows:

$$\begin{array}{c} \\ L_1 \\ L_2 \\ L_3 \end{array} \begin{array}{c} \begin{array}{ccc} A & B & C \end{array} \\ \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix} \end{array}$$

Also assume that matrices of yield response and yield potential are as follows:

$$\mu_i = \begin{bmatrix} 0.5 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1.5 \end{bmatrix}, \hat{y}_i = \begin{bmatrix} 1 & 1.5 & 2 \\ 1 & 1.5 & 2 \\ 1 & 1.5 & 2 \\ 1 & 1.5 & 2 \\ 1 & 1.5 & 2 \\ 1 & 1.5 & 2 \\ 1 & 1.5 & 2 \\ 1 & 1.5 & 2 \\ 1 & 1.5 & 2 \\ 1 & 1.5 & 2 \end{bmatrix}$$

These matrices show that variety *A* has a yield potential of 1 and yield response of 0.5 to characteristic L_1. Variety *B* has a yield potential of 1.5 and yield response of 1 to characteristic L_2, and variety *C* has a yield potential of 2 and yield response of 1.5 to characteristic L_3.

Assuming L_1, L_2, and L_3 correspond to θ_1, θ_2, and θ_3, respectively (i.e. a one-to-one relationship), yield levels of varieties A, B and C in parcels $j = 1, \cdots, 10$ can be obtained as follows:

$$\begin{bmatrix} 1 & 1.5 & 2 \\ 1 & 1.5 & 2 \\ 1 & 1.5 & 2 \\ 1 & 1.5 & 2 \\ 1 & 1.5 & 2 \\ 1 & 1.5 & 2 \\ 1 & 1.5 & 2 \\ 1 & 1.5 & 2 \\ 1 & 1.5 & 2 \\ 1 & 1.5 & 2 \end{bmatrix} - \begin{bmatrix} 0.23 & 0.45 & 0.39 \\ 0.29 & 0.04 & 0.19 \\ 0.25 & 0.73 & 0.33 \\ 0.48 & 0.41 & 0.45 \\ 0.34 & 0.90 & 0.23 \\ 0.96 & 0.09 & 0.53 \\ 0.86 & 0.96 & 0.89 \\ 0.52 & 0.85 & 0.85 \\ 0.71 & 0.22 & 0.98 \\ 0.20 & 0.19 & 0.50 \end{bmatrix} \begin{bmatrix} 0.5 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1.5 \end{bmatrix} \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix} = \begin{array}{c} \\ 1 \\ 2 \\ 3 \\ 4 \\ 5 \\ 6 \\ 7 \\ 8 \\ 9 \\ 10 \end{array} \!\!\begin{array}{c} \begin{array}{ccc} A & B & C \end{array} \\ \begin{bmatrix} 0.89 & 1.05 & 1.42 \\ 0.85 & 1.46 & 1.72 \\ 0.87 & 0.77 & 1.51 \\ 0.76 & 1.09 & 1.33 \\ 0.83 & 0.60 & 1.66 \\ 0.52 & 1.41 & 1.21 \\ 0.57 & 0.54 & 0.67 \\ 0.74 & 0.65 & 0.73 \\ 0.65 & 1.28 & 0.53 \\ 0.90 & 1.31 & 1.25 \end{bmatrix} \end{array} = Yield\ levels$$

The yield of variety A in parcel 1 is determined by the yield potential of variety A, which is 1, and the interaction of characteristics of parcel 1, $[0.23, 0.45, 0.39]$, the yield response of variety A, $\begin{bmatrix} 0.5 \\ 0 \\ 0 \end{bmatrix}$, and characteristics of variety A, $\begin{bmatrix} 1 \\ 0 \\ 0 \end{bmatrix}$. The yield levels of varieties A, B, and C in parcels 1 to 10 are determined in a similar fashion.

There is a pattern in the yield levels matrix above. Each variety reaches its yield potential $\hat{y}_i$ at a certain parcel of land. Variety A, for example, yields most in parcel 10 (Y_{10A}=0.90). The second-best parcel of land for variety A is parcel 1 (Y_{1A}=0.89). By following this pattern, one can see that as the area of one variety expands from the best-suited parcel to the second best, third best and so on, the average yield of that variety drops. With no scale economies in producing seed, this does not need to occur because the market will produce an ideal variety for each parcel of land (Lancaster, 1990). The existence of fixed costs and scale economies on the supply side, however, results in fewer varieties than the number of parcels of land. This implies that each variety will be used in some parcels of land other than its best-suited parcel. As a result, seed varieties lose their marginal productivity as their area expands to parcels other than their ideal parcel of land.[7]

Assuming that land is uniformly distributed between the best-suited and worst-suited parcels, and that land parcels are arbitrarily small, then the decline in yield of each variety will be a

[7] The area does not necessarily expand around the highest-yielding parcel.

continuous linear function of the amount of land allocated to that variety. Thus, the relationship between yield and area of variety i can be written as:

$$(2.1) \quad Y_i = \hat{y}_i - \mu_i X_i$$

where Y_i is the yield of variety i per acre, $\hat{y}_i$ the potential yield of variety i per acre (i.e. yield at the best-suited parcel), X_i the area or number of parcels allocated to variety i, and μ_i is the yield decrease of variety i as its area expands by one unit. This relationship holds for each column of the yield levels matrix $[Y_{ji}]_{m\times n}$. Equation 2.1 indicates that each variety i yields most at a particular parcel of land and its yield drops in a linear fashion by the rate of μ_i as the area X_i allocated to variety i expands.[8] In other words, μ_i, or the yield response of a variety to a change in its corresponding land characteristic, reflects the degree of specificity of variety i for different parcels of land. Hereafter μ_i will be referred to as degree of specificity of variety i. A larger μ_i means the yield of variety i drops faster as the area expands and this implies variety i is more specific to particular parcels of land and *vice versa*.

The surplus created from variety i in each parcel $j = 1, \cdots, 10$ can be formulated as follows:

$$(2.2) \quad S_{ij} = P.Y_{ij} - W_i \,;\, i = A, B, C \; and \; j = 1, \cdots, 10$$

where S_{ij} is the surplus created from variety i in each parcel j, P is the output price, Y_{ij} is the yield of variety i in parcel j, and W_i is the price of variety i. Assuming output price P is equal to 1 and all three varieties are equally priced at $W_i = 0.1$, the surplus (S_{ij}) in each parcel $j = 1, \cdots, 10$ is as follows:

[8] With non-uniform distribution of parcels of land, the relationship between yield and area of variety i (equation 2.1) becomes non nonlinear, and with parcels of land that are not arbitrarily small the continuous linear function turns into a step function.

$$Surplus\ levels(S_{ij}):\ \begin{array}{c|ccc} & A & B & C \\ \hline 1 & 0.79 & 0.95 & 1.32 \\ 2 & 0.75 & 1.36 & 1.62 \\ 3 & 0.77 & 0.67 & 1.41 \\ 4 & 0.66 & 0.99 & 1.23 \\ 5 & 0.73 & 0.50 & 1.56 \\ 6 & 0.42 & 1.31 & 1.11 \\ 7 & 0.47 & 0.44 & 0.57 \\ 8 & 0.64 & 0.55 & 0.63 \\ 9 & 0.55 & 1.18 & 0.43 \\ 10 & 0.80 & 1.21 & 1.15 \end{array}\ ;i = A, B, C\ and\ j = 1, \cdots, 10$$

Highlighted cells show the varieties that return the highest surplus level for each parcel of land. On any given parcel of land there is one variety that creates higher producer surplus (i.e. return to fixed factors of production) than any other variety for that parcel of land.[9] Farmers pick the variety that provides the highest surplus (S_i) for their parcel of land. In parcel 1, for example, variety C offers the highest surplus while in parcel 8 variety A returns the highest surplus.

Figure 2.2 provides a graphical analysis corresponding to the matrix analysis that is presented above. Figure 2.2 depicts how parcels of land with independent characteristics are allocated to two equally priced varieties of seed that have the same yield potential and degree of specificity of 1 and 0.5, respectively. Each of the 100 red points on the graph represents a parcel of land. The locus of each parcel is determined by the yield levels of varieties 1 and 2 in that parcel. Yield levels of each variety are randomly distributed between 0.5 and 1 (i.e. $Y_i \sim u(\hat{y}_i - \mu_i, \hat{y}_i)$). The green line represents $P.Y_1$-W_1= $P.Y_2$-W_2 for the case of W_1=W_2, so it divides the area between Y_1 and Y_2 axes to two equal size triangles. For all parcels of land above the green curve $P.Y_1$-W_1 is greater than $P.Y_2$-W_2. For all parcels underneath the green line $P.Y_2$-W_2 is greater than $P.Y_1$-W_1. Therefore, all parcels above the green line choose variety 1 over variety 2 and all parcels underneath the green line choose variety 2 over variety 1. It is obvious that in the absence of variety 2 all the points between Y_1 and Y_2 axes collapse on the Y_1 axis.

[9] This is similar to "ideal goods" for different groups of consumers in consumption-side hybrid models.

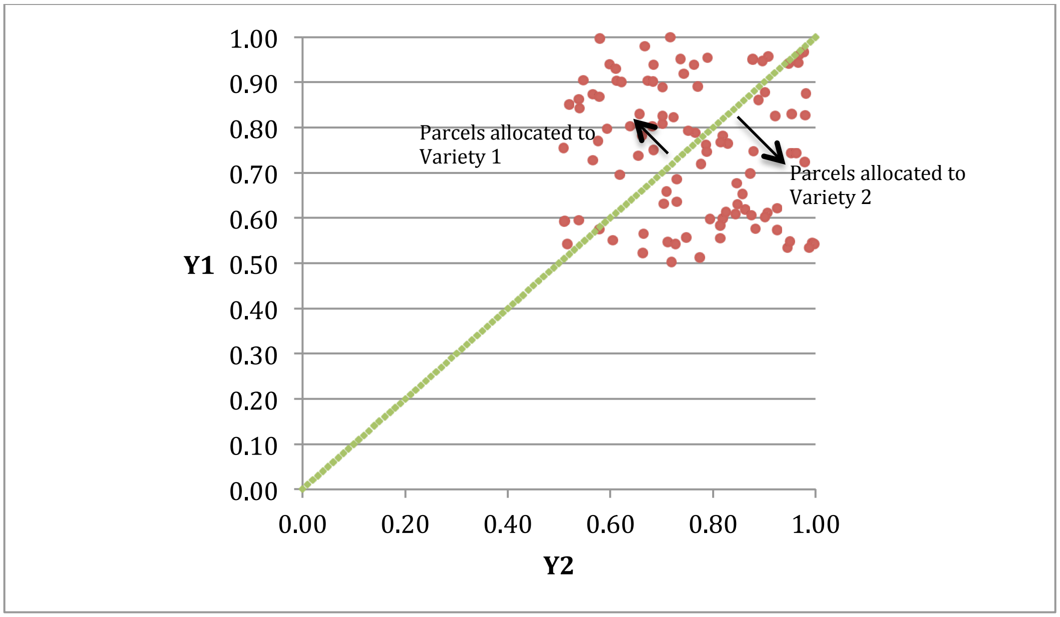
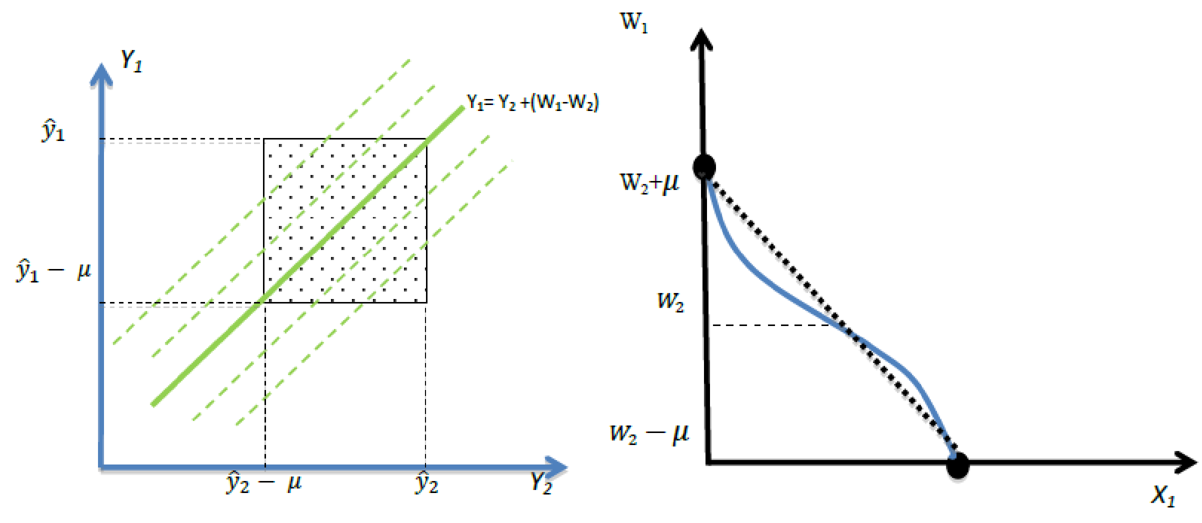


Figure 2. 2. Allocation of Parcels of Land to Two Equally Priced Varieties with Same Yield Potentials.

Given the matrix and the graphical analyses above, now an algebraic analysis can be presented. Ideally, surplus needs to be maximized for each parcel of land. Appendix 2.C presents the Lagrangean corresponding to the surplus maximization problem for each parcel of land. This approach, however, is analytically difficult, if not impossible, to solve for *n* varieties. Figure 2.3 shows how demand curves for the case of only two varieties can be found. Panel *i* of Figure 2.3 is similar to Figure 2.2. As shown in panel *i*, as price of variety 1 (W_2) increases while price of variety 2 (W_2) is fixed, the price line shifts up in a parallel fashion and some parcels of land switch from variety 1 to variety 2. However, as the green curve moves higher and higher, fewer and fewer parcels switch to variety 2. This is because the land characteristics that varieties 1 and 2 correspond to are independent and, thus, parcels of land are spread over the space in between Y_1 and Y_2 axes with the same density. Similarly, each time price of variety 1 is decreased, fewer and fewer parcels switch to this variety. This relationship between change in price of a variety and number of parcels that switch implies a non-linear demand curve for the variety. This demand curve is illustrated in Panel *ii* of Figure 2.3.



Panel i- Allocation of Parcels of Land to Two Varieties *Panel ii-Demand for Variety 1*

Figure 2. 3. Exact Non-Linear Demand for the Case of Independent Land Characteristics.

Appendix 2.C derives the equation for this non-linear demand curve as follows:

$$\begin{cases} X_1 = 0 \; for \; (\mu - W_1 + W_2) < 0 \\ X_1 = \frac{(\mu - W_1 + W_2)^2}{2\mu^2} \; for \; W_1 \geq W_2 \; and \; (\mu - W_1 + W_2) \geq 0 \\ X_1 = 1 - \frac{(\mu - W_2 + W_1)^2}{2\mu^2} \; for \; W_1 \leq W_2 \; and \; (\mu - W_2 + W_1) \geq 0 \\ X_1 = 1 \; for \; (\mu - W_2 + W_1) < 0 \end{cases}$$

This exact demand equation is difficult to generalize to more than two varieties. An alternative approach is presented below. This approach results in an approximate demand curve that is depicted by the dashed downward sloping curve in Figure 2.3. Appendix 2.C discusses the relationship between the exact and approximate demand curves in more depth.

Farmer f's surplus or return to fixed factors of production from growing variety i is as follows:

$$s_{fi} = P \int_0^{X_{fi}} Y_i dX - W_i X_{fi} \quad (2.3)$$

where s_{fi} is farmer f's surplus from variety i, P is output price, X_{fi} is the area farmer f allocates to variety i, Y_i is the yield of variety i per acre, and W_i is the price of variety i.[10] With the perfectly competitive agriculture industry assumption, maximizing the surplus for each individual farmer is equivalent to maximizing the total surplus for all the farmers in the region subject to the corresponding land constraint.[11] The farmers' total surplus from varieties $i = 1, \dots, n$ is as follows:

$$S = \sum_{f=1}^{F} \sum_{i=1}^{n} s_{fi} = \sum_{i=1}^{n} s_i = \sum_{i=1}^{n} (P \int_0^{X_i} Y_i dX - W_i X_i)$$

Therefore, the objective function for the whole region can be written as:

$$(2.4) \quad Max_{X_i} S = \sum_{i=1}^{n} s_i = \sum_{i=1}^{n} (P \int_0^{X_i} Y_i dX - W_i X_i) \quad s.t. \sum_{i=1}^{n} X_i = \bar{X} = 1$$

Without lack of generality, the total available land $\bar{X}$ is assumed to be equal to 1. By substituting equation 2.1 in 2.4, the Lagrangean function corresponding to the above maximization problem can be formulated as follows:

$$(2.5) \quad \mathcal{L}_S = \sum_{i=1}^{n} \left[P \int_0^{X_i} (\hat{y}_i - \mu_i X_i) dX - W_i X_i + \lambda (1 - \sum_{i=1}^{n} X_i) \right]$$

where λ, the Lagrangean multiplier, represents the shadow value of the last (i.e. least productive) parcel of land allocated to each variety.

The Lagrangean of 2.5 maximizes the region's total surplus by translating the demand for *n* differentiated varieties into demand for one commodity, land, and using a single land constraint to find the optimum market share for each variety such that the shadow value of the last parcel of land allocated to each variety equals λ.

The first-order conditions (FOCs) for maximization of 2.5 are:

[10] It is assumed that there are a sufficiently large number of parcels of land such that the variable X_i, although a discrete variable, can be used in the integral. With a sufficiently large number of parcels, this integral provides a close approximation.

[11] According to Ackerberg et al. (2007), the "outside" alternative can be added to a model through an individual specific constant term without changing the preferences over products. Thus, this study takes a similar approach to Ackerberg et al. (2007, page 4186) and does not include an outside alternative in the model.

$$(2.6) \quad \begin{cases} \frac{\partial \mathcal{L}_S}{\partial X_i} = 0 \Longrightarrow P(\hat{y}_i - \mu_i X_i) - W_i = \lambda \\ \frac{\partial \mathcal{L}_S}{\partial \lambda} = 0 \Longrightarrow \sum_{i=1}^{n} X_i = 1 \end{cases}$$

The FOCs of the Lagrangean ensure that surplus in the last (marginal) parcel of land that is allocated to each variety is equal to the opportunity cost of land (λ). That is, the maximum willingness to pay for the marginal parcel of land that is allocated to each variety is equal to the opportunity cost of land (i.e. its true production scarcity). This satisfies the condition for a Pareto optimum and ensures that total surplus from all the varieties is maximized.

Notice that the land constraint implies that total land allocated to this crop must equal $\sum_{i=1}^{n} X_i = \bar{X} = 1$. If there are any abandoned parcels of land, this condition does not hold. However, this condition holds as long as the land constraint is binding. Land constraint is binding as long as land rents are positive.

Without lack of generality, it is assumed that output price *P*=1 in 2.6. Now FOCs of equation 2.6 can be written as follows:

$$(2.7) \quad \begin{cases} \hat{y}_1 - \mu_1 X_1 - W_1 = \hat{y}_2 - \mu_2 X_2 - W_2 = \cdots = \hat{y}_n - \mu_n X_n - W_n = \lambda \\ X_1 + X_2 + \cdots + X_n = 1 \end{cases}$$

Demand for each seed variety can be obtained by solving the *n+1* equations for *n+1* unknowns in the FOCs. In section 2.5, it is shown that the demand system introduced above is consistent with economic theory. It is important to mention that the above FOCs are driven for the case of full information. That is, it is assumed that farmers have perfect information about the yield potential and degree of specificity of all varieties.

2.4.3. Supply of seed

In this section, the FOCs of equation 2.7 are used to obtain the demand for varieties of seed and to solve the seed producers' profit-maximization problem. The Nash equilibrium is first found for two varieties with two unique characteristics and then for three varieties with three unique characteristics. The process is continued until the model is solved for *n* varieties with *n* characteristics. For simplicity, it is assumed that all seed varieties have the same degree of specificity. That is, $\mu_i = \mu$ for $i = 1, \dots, n$.

Period 1: In period 1 variety 1 is the only variety in the market. Hybrid technology is introduced to the market through this variety for the first time. The seed producer has market power over this new "drastic innovation" and prices variety 1 at a monopoly level (Moschini and Lapan, 1997). [12] Schumpeter (1939) argues that the innovation-originated market power creates temporary above-normal profit that is necessary to "induce" innovation. This new innovation acts similar to a wave that creates a dynamic cycle in the economy. On the back of this wave, however, innovations of smaller magnitude (i.e. "non-drastic innovations" in Moschini and Lapan's terms) are performed by the original entrepreneur or by imitators. Schumpeter suggests that these smaller non-drastic innovations, which are cumulatively built on the original drastic innovation, compete with the original drastic innovation. As a result, the original entrepreneur can no longer charge a monopoly price and the original drastic innovation turns into a non-drastic innovation (Schumpeter, 1939).

Variety 1 offers characteristic L_1. Therefore, the vector of characteristics for variety 1 is $L_1 = \{1,0,0, \dots ,0\}$. First element in L_1 corresponds to at least one element, say θ_{1j}, in $\theta_j \in \{\theta_{1j}, \theta_{2j}, \dots \theta_{nj}\}$. Variety 1 is the ideal variety for the parcel of land that is characterized by the highest relative θ_{1j} in $\theta_j \in \{\theta_{1j}, \theta_{2j}, \dots \theta_{nj}\}$. However, when variety 1 is the only available variety, those with low relative θ_{1j} have to buy variety 1 even though it is not their ideal variety.

Producer of variety 1 is a monopolist. This firm sets the price where profit is maximized. It is assumed that yield of variety 1 in the least productive parcel of land is high enough that maximum willingness to pay in this parcel is equal to or larger than the monopoly price. This is to ensure that all canola farmers buy this variety and no parcels of land are left abandoned. [13]

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[12] An innovation is drastic if it leads to "unconstrained monopoly price of the innovated input" and is nondrastic if "the monopolist's pricing decision is constrained by the threat of competition" (Moschini and Lapan, 1997).

[13] Given the uniform distribution of the yield levels ($Y_i \sim u(\hat{y}_i - \mu_i, \hat{y}_i)$), maximum willingness to pay in the least productive parcel allocated to variety 1 is equal to $P(\hat{y}_1 - \mu_1)$. Assuming output price is equal to 1 and marginal cost of the seed producer is equal to zero, if $\frac{\hat{y}_1}{2} = \mu_1$ then monopoly price will be equal to $W_1 = (\hat{y}_1 - \mu_1) = \frac{\hat{y}_1}{2}$ and market share will be equal to 1. This ensures that all canola farmers buy this variety.

Period 2: In *period 2*, variety 1 (the original innovation) is in the market and a seed producer releases variety 2 into the market.[14] Upon entry of variety 2 firms engage in competition. Variety 2 offers characteristic L_2. That is, the vector of characteristics for variety 2 is $L_2 = \{0,1,0,\ldots,0\}$. The second element in L_2 corresponds to at least one element, say θ_{2j}, in $\theta_j \in \{\theta_{1j}, \theta_{2j}, \ldots \theta_{nj}\}$. Variety 2 is the ideal variety for the parcel of land that is characterized by the highest relative θ_{2j} in $\theta_j \in \{\theta_{1j}, \theta_{2j}, \ldots \theta_{nj}\}$. However, when varieties 1 and 2 are the only available varieties, those farmers with low relative θ_{1j} and θ_{2j} have to buy varieties 1 or 2 even though neither is their ideal variety.

Varieties 1 and 2 are the same except for the fact that variety 1 offers characteristic L_{11} while variety 2 offers characteristic L_{22}.[15] Varieties 1 and 2 compete with respect to two characteristics, L_{11} and L_{22}. The FOCs of equation 2.7 for two varieties can be written as follows:

$$\hat{y}_1 - \mu X_1 - W_1 = \hat{y}_2 - \mu X_2 - W_2$$

$$X_1 + X_2 = 1$$

Demand for varieties 1 and 2 are obtained by solving the above equations for the two unknowns X_1 and X_2:

(2.8-a) $$X_1 = \frac{1}{2} + \frac{(\hat{y}_1 - W_1) - (\hat{y}_2 - W_2)}{2\mu}$$

(2.8-b) $$X_2 = \frac{1}{2} + \frac{(\hat{y}_2 - W_2) - (\hat{y}_1 - W_1)}{2\mu}$$

The above demands are used in the seed producers' profit-maximization problems as follows:

$$\pi_1 = W_1 X_1 - FC = W_1\left[\frac{1}{2} + \frac{(\hat{y}_1 - W_1) - (\hat{y}_2 - W_2)}{2\mu}\right] - FC \ , \frac{\partial \pi_1}{\partial W_1} = 0$$

$$\pi_2 = W_2 X_2 - FC = W_2\left[\frac{1}{2} + \frac{(\hat{y}_2 - W_2) - (\hat{y}_1 - W_1)}{2\mu}\right] - FC \ , \frac{\partial \pi_2}{\partial W_2} = 0$$

[14] It is assumed that the producer of variety 1 cannot deter entry of variety 2 via limit pricing since both firms have similar cost structures (i.e. zero marginal and equal fixed cost levels). This holds for entry of varieties *3, 4, …, n* as well.
[15] One could assume that both varieties originate from one generic variety. Variety 1 is the generic variety with the characteristic L_{11} embodied in it, whereas variety 2 is the generic variety with the characteristic L_{22} embodied in it.

Bertrand-Nash equilibrium prices, quantities and profits resulting from the above profit maximization problems are as follows:

$W_1 = \frac{\hat{y}_1 - \hat{y}_2}{3} + \mu$, $W_2 = \frac{\hat{y}_2 - \hat{y}_1}{3} + \mu$

$X_1 = \frac{1}{2}(1 + \frac{\hat{y}_1 - \hat{y}_2}{3\mu})$, $X_2 = \frac{1}{2}(1 + \frac{\hat{y}_2 - \hat{y}_1}{3\mu})$

$\pi_1 = \frac{(3\,\mu + \hat{y}_1 - \hat{y}_2)^2}{18\mu} - FC$, $\pi_2 = \frac{(3\,\mu - \hat{y}_1 + \hat{y}_2)^2}{18\mu} - FC$

Period 3: In the 3rd period, varieties 1 and 2 are in the market. The producer of variety 3 foresees a positive willingness to pay for a new differentiated product and, therefore, releases variety 3 into the marketplace. This variety differentiates itself with respect to a new characteristic, L_{33}.[16] The vector of characteristics for variety 3 is $L_3 = \{0,0,1, \dots ,0\}$. In period 2, variety 3 did not exist and buyers who were interested in characteristic L_{33} could not buy it. Therefore, a portion of buyers reveals their preference for L_{33} by switching from varieties 1 and 2 to variety 3. This means smaller demand for varieties 1 and 2 in period 3 compared to period 2. Appendix 2.A discusses this in more depth.

The FOCs of equation 2.7 for three varieties imply the following conditions:

$\hat{y}_1 - \mu X_1 - W_1 = \hat{y}_2 - \mu X_2 - W_2$

$\hat{y}_2 - \mu X_2 - W_2 = \hat{y}_3 - \mu X_3 - W_3$

$X_1 + X_2 + X_3 = 1$

Market shares for varieties 1, 2 and 3 are obtained by solving the above equations for the three unknowns X_1, X_2, X_3:

(2.9-a) $X_1 = \frac{1}{3} + \frac{2(\hat{y}_1 - W_1) - (\hat{y}_2 - W_2) - (\hat{y}_3 - W_3)}{3\mu}$

(2.9-b) $X_2 = \frac{1}{3} + \frac{2(\hat{y}_2 - W_2) - (\hat{y}_1 - W_1) - (\hat{y}_3 - W_3)}{3\mu}$

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[16] The new variety does not have the characteristics L_{11} and L_{22} that were embodied in varieties 1 and 2 but has characteristic L_{33} that differentiates it from existing varieties on a new dimension.

(2.9-c) $X_3 = \frac{1}{3} + \frac{2(\hat{y}_3 - W_3) - (\hat{y}_1 - W_1) - (\hat{y}_2 - W_2)}{3\mu}$

Best response functions (BRFs) are obtained by substituting X_1, X_2, and X_3 in the following profit-maximization problems:

$$\pi_1 = W_1 X_1 - FC = W_1[\frac{1}{3} + \frac{2(\hat{y}_1 - W_1) - (\hat{y}_2 - W_2) - (\hat{y}_3 - W_3)}{3\mu}] - FC \,, \frac{\partial \pi_1}{\partial W_1} = 0$$

$$\pi_2 = W_2 X_2 - FC = W_2[\frac{1}{3} + \frac{2(\hat{y}_2 - W_2) - (\hat{y}_1 - W_1) - (\hat{y}_3 - W_3)}{3\mu}] - FC \,, \frac{\partial \pi_2}{\partial W_2} = 0$$

$$\pi_3 = W_3 X_3 - FC = W_3 \left[\frac{1}{3} + \frac{2(\hat{y}_3 - W_3) - (\hat{y}_1 - W_1) - (\hat{y}_2 - W_2)}{3\mu}\right] - FC \,, \frac{\partial \pi_3}{\partial W_3} = 0$$

Bertrand-Nash equilibrium results are obtained by solving the BRFs simultaneously:

$$W_1 = \frac{2\hat{y}_1 - \hat{y}_2 - \hat{y}_3}{5} + \frac{\mu}{2}, W_2 = \frac{2\hat{y}_2 - \hat{y}_1 - \hat{y}_3}{5} + \frac{\mu}{2}, W_3 = \frac{2\hat{y}_3 - \hat{y}_1 - \hat{y}_2}{5} + \frac{\mu}{2}$$

$$X_1 = \frac{1}{3}(1 + \frac{4\hat{y}_1 - 2\hat{y}_2 - 2\hat{y}_3}{5\mu}), X_2 = \frac{1}{3}(1 + \frac{4\hat{y}_2 - 2\hat{y}_1 - 2\hat{y}_3}{5\mu}), X_3 = \frac{1}{3}(1 + \frac{4\hat{y}_3 - 2\hat{y}_1 - 2\hat{y}_2}{5\mu})$$

$$\pi_1 = \frac{(5\,\mu + 4\hat{y}_1 - 2\hat{y}_2 - 2\hat{y}_3)^2}{150\mu} - FC \,, \pi_2 = \frac{(5\,\mu + 4\hat{y}_2 - 2\hat{y}_1 - 2\hat{y}_3)^2}{150\mu} - FC \,, \pi_3 = \frac{(5\,\mu + 4\hat{y}_3 - 2\hat{y}_1 - 2\hat{y}_2)^2}{150\mu} - FC$$

The critical assumption is that variety 3 competes with both varieties 1 and 2. This is because variety 3 competes with varieties 1 and 2 on a new dimension (i.e. with respect to a new characteristic). Variety 3 is differentiated from varieties 1 and 2 with respect to characteristic L_{33}, a characteristic that neither 1 nor 2 embody.

This study assumes that seed producers' cost structure consists of a positive fixed cost and a zero marginal cost. If the discounted value of revenues from product 3 over time is greater than the fixed cost, then there is an incentive for the seed producer to create the L_{33} characteristic and introduce variety 3 to the market. As shown in the profit equation above, if $\hat{y}_3 \geq \hat{y}_1$ and $\hat{y}_3 \geq \hat{y}_2$ then revenue is greater than zero. Even if $\hat{y}_3 < \hat{y}_1$ and $\hat{y}_3 < \hat{y}_2$ it is still possible to have a positive revenue for product 3. That is, if the yield potential of variety 3 is equal to or even smaller than the yield potential of variety 1 and variety 2, it is still possible for variety 3 to profitably enter the market by offering a new characteristic if, and only if, the discounted value of revenues is larger than fixed cost. Nevertheless, a higher yield potential will accommodate higher profit levels for the new variety. The expected profit creates the incentive to innovate.

***Period t (General Model)*:** In period *t*, the new variety, *n*, enters the market. This variety reveals the n^{th} characteristic L_{nn} and adds the n^{th} dimension to the model. The *n*-dimensional choice set can perfectly capture buyers' preferences for *n* characteristics. Assuming there is no exit, all the varieties that have previously entered the market still exist. In such a case the variety introduced in time *t* competes with all the existing varieties introduced in times *1, 2, 3,…, t-1*. Subscript *t* is used to refer to the time period and not to be confused with number of varieties *n*.

By generalizing the results of periods 2 and 3, the price, market share and profit of a variety introduced at time *t* are as follows:

(2.10) $$W_t = \frac{\sum_{i=1}^{n}(\hat{y}_t - \hat{y}_i)}{2n-1} + \frac{\mu}{n-1} \qquad \forall\, 1 \leq t \leq n \; and \; t \neq i.$$

(2.11) $$X_t = \frac{1}{n}\left(1 + \frac{(n-1)\sum_{i=1}^{n}(\hat{y}_t - \hat{y}_i)}{(2n-1)\mu}\right) \qquad \forall\, 1 \leq t \leq n \; and \; t \neq i.$$

(2.12) $$\pi_t = \frac{\left[n\sum_{i=1}^{n}(\hat{y}_t - \hat{y}_i) + (2n-1)\mu\right]^2}{(2n-1)^2(n-1)n\mu} - FC \qquad \forall\, 1 \leq t \leq n \; and \; t \neq i.$$

W_t, X_t, and π_t can be used to calculate the price of all the varieties that have been introduced in times 1 to *t*. For example, when calculating the price of variety 5 at time period 5, one needs to set *t=5*, *n=5*, and *i=1, 2, 3, 4, 5*. In order to calculate the price of variety 3 in period 5, one needs to set *t=3*, *n*=5, and *i=1, 2, 3, 4, 5*.

The price, demand and profit equations above correspond to economic intuition. The price of a new variety is a positive function of its own yield potential and the price of its rivals and a negative function of the yield potential of its rivals. Market share or demand for a new variety is a positive function of its own yield potential and its rivals' price and a negative function of its own price and yield potential of its rivals. Demand for a variety is also a function of number of varieties in the market. The profit of a new variety is a positive function of its own yield potential and the price of its rivals and a negative function of the yield potential of its rivals. Equation 2.12 also implies that even with a yield potential that is lower than its rivals, a variety still has a chance to profitably enter the market by introducing a new characteristic if, and only if, the discounted value of revenues over time is greater than the fixed cost.

Another interesting case is when yield potential does not improve. In this case all varieties will have the same yield potential. As a result, price and market share become a function of only degree of specificity μ and number of firms *n*. Profit level also becomes a function of degree of specificity μ, number of firms *n*, and fixed cost *FC*.

Section 2.5 explores some properties of the model that add novel contributions to the literature on sequential innovation.

2.5. Propositions

The model presented in the previous section, if not the first, is perhaps one of the first monopolistic competition models of analyzing product variety that incorporates competition among *n* production inputs with *n* differentiating characteristics. Some properties of this new model need more exploration. This section attempts to briefly discuss some properties of the theoretical model through algebraic proofs. These properties will be referred to as propositions.

Proposition 1: Increase in variety (i.e. increase in number of seed varieties) improves farmers' total surplus, ceteris paribus.

Proof: Here, it is shown that seed buyers' surplus is a positive function of the number of available varieties. In equation 2.1, the relationship between yield of a variety and its area is described as follows:

(2.1) $Y_i = \hat{y}_i - \mu_i X_i$

where Y_i is yield of variety *i* per acre, $\hat{y}_i$ potential yield of variety *i* per acre, X_i area allocated to variety i, and μ_i is the degree by which variety *i* loses its yield as area expands. Equation 2.2 could be rewritten for all farmers that use variety *i* as follows:

(2.13) $s_i = PX_iY_i - W_iX_i$

where s_i is the farmers' surplus from variety i, P is the output price, X_i is the area allocated to variety i and W_i is the price of variety i. Assume that $\bar{X}$ acres of land are equally shared among *n* available varieties.[17] That is,

(2.14) $$X_i = \frac{\bar{X}}{n} \qquad \forall\, 1 \leq i \leq n.$$

Assume μ_i is a constant μ for all available *n* varieties. By substituting equations 2.1 and 2.14 in equation 2.13 surplus from variety *i* is as follows:

$$s_i = P\frac{\bar{X}}{n}(\hat{y}_i - \mu\frac{\bar{X}}{n}) - W_i\frac{\bar{X}}{n}$$

Total profit for *n* varieties is then as follows:

(2.15) $$S = P\bar{X}\hat{y}_i - P\mu\frac{\bar{X}^2}{n} - W_i\bar{X}$$

In order to find the effect of an increase in the number of varieties on total surplus the derivative of equation 2.15 is taken with respect to *n*:

(2.16) $$\frac{\partial s}{\partial n} = P\mu\frac{\bar{X}^2}{n^2} > 0$$

As shown in 2.16, the farmers' aggregate surplus increases with the number of available varieties. This is evidence of unbounded gains from variety that is also shown in Neo-Chamberlinian models, such as that of Dixit and Stiglitz (1977).[18]

Further, equation 2.16 shows that the increase in the buyers' aggregate gain from variety is larger with a higher μ. That is, the buyers' aggregate gain from variety is higher with more specific products (i.e. products with higher degrees of horizontal differentiation). This also means that a region with more heterogeneous pieces of land benefits more from an increase in the number of varieties.

[17] This is possible when all varieties have the same yield potential level.
[18] According to Lancaster (1990), in Dixit and Stiglitz's model "the consumer is always better off spending *1/n*th of his group budget on each of *n* goods than spending *1/(n-1)*th of the budget on each of *n-1* goods, implying an insatiable taste for variety."

Proposition 2: Market share for a superior variety increases as the degree of specificity decreases, ceteris paribus.

Proof: The derivative of equation 2.11 with respect to degree of specificity is as follows:

(2.17) $\frac{\partial X_t}{\partial \mu} = \frac{1}{n}\left(-\frac{(2n-1)(n-1)\sum_{i=1}^{n}(\hat{y}_t - \hat{y}_i)}{(2n-1)^2\mu^2}\right) < 0 \qquad \forall\ 1 \le t \le n, t \neq i, and\ \hat{y}_t > \hat{y}_i.$

Market share for higher quality varieties decreases as varieties become more specific. Also, it is worth noting that as varieties become more specific, the number of varieties in the market increases. However, finding the relationship between the degree of specificity and the number of firms is mathematically intractable. Further evidence of this is obtained via numerical simulations in sections 3.2 and 3.3.3 of Chapter 3.

Proposition 3: The more specific varieties are, the higher they can be priced, ceteris paribus.

Proof: The derivative of equation 2.10 with respect to the degree of specificity of varieties is as follows:

(2.18) $\frac{\partial W_t}{\partial \mu} = \frac{1}{n-1} > 0$

A specific variety is a variety that suits a specific group of farmers. In other words, it contains a unique characteristic that not all farmers require. The positive sign of 2.18 suggests that the more specific varieties are, the higher they can be priced.

Proposition 4: If potential yield sequentially improves with new varieties, a higher rate of yield improvement results in a higher market share for the superior variety, ceteris paribus.

Proof: To incorporate sequential innovation, it is assumed that the yield potential of new varieties improves over time with rate of *k* such that:

(2.19) $\hat{y}_t = \hat{y}_{t-1} + k$

where *t* represents time. Incorporating equation 2.19 into equation 2.11 results in:

(2.20) $X_t = \frac{1}{n}\left(1 + \frac{(n-1)(nt-\sum_{i=1}^{n} i)k}{(2n-1)\mu}\right) \ \forall\, 1 \le t \le n.$

where X_t is market share of the variety introduced at time t and k is the rate of yield potential growth. The derivative of equation 2.20 with respect to the rate of yield potential growth is as follows:

(2.21) $\frac{\partial X_t}{\partial k} = \frac{1}{n}\left(\frac{(n-1)(nt-\sum_{i=1}^{n} i)}{(2n-1)\mu}\right) \quad \forall\, 1 \le t \le n.$

Equation 2.21 is greater than zero for all $t=n$. That is, a higher rate of yield potential improvement results in a higher market share for the newest variety, which also has the highest yield potential level. For $t<n$, $\frac{\partial X_t}{\partial k}$ could be greater or smaller than zero depending on age or relative yield of the variety. With a higher rate of yield potential improvement, the superior (i.e. the newest) variety always obtains a higher market share than it would with a lower rate. However, this also means that the older varieties with lower yield potential obtain lower market shares than they would with a lower rate of yield potential improvement. This is because the difference between the yield potential of the superior and the inferior varieties is greater when rate of yield potential improvement is higher. In other words, with a higher rate of yield potential improvement, the difference between the yield potential of the varieties increases and that changes the distributions of market shares in favour of the varieties with higher quality. For example, if there are 4 varieties in the market, then $\frac{\partial X_t}{\partial k}$ will be positive for varieties 4 and 3 and negative for varieties 1 and 2. That is, the difference between the yield potential of the 4 varieties increases and that changes the distributions of market shares in favour of the two higher quality varieties.

Proposition 5: Higher rate of yield potential improvement results in a higher price for the superior variety, ceteris paribus.

Proof: Similar to proposition 4, it is assumed that the yield potential of new varieties improves over time with rate of k such that:

(2.19) $\hat{y}_t = \hat{y}_{t-1} + k$

By incorporating equation 2.19 into equation 2.10 it can be written as follows:

$$(2.22) \quad W_t = \frac{(nt-\sum_{i=1}^{n} i)k}{(2n-1)} + \frac{\mu}{n-1} \;\; \forall\, 1 \le t \le n.$$

The derivative of equation 2.22 with respect to the yield (potential) growth rate is as follows:

$$(2.23) \quad \frac{\partial W_t}{\partial k} = \frac{(nt-\sum_{i=1}^{n} i)}{(2n-1)} \;\; \forall\, 1 \le t \le n.$$

Equation 2.23 is greater than zero for all $t=n$. That is, a higher rate of yield potential improvement results in a higher price for the newest variety, which is also the variety with the highest yield potential level. For $t<n$, $\frac{\partial W_t}{\partial k}$ could be greater or smaller than zero depending on the age or relative yield of the variety. Newer varieties that are introduced later in time and have higher yield potential levels will experience a higher price at higher rates of yield potential improvement and older varieties with lower yield potential levels will experience a lower price at higher rates of yield potential improvement. This is because a higher rate of yield potential improvement increases the difference between the yield potential of the varieties and that changes the relative prices such that higher quality varieties receive relatively higher prices and lower quality varieties receive relatively lower prices compared to the case of lower rate of yield potential.

Combining the findings of propositions 4 and 5 has interesting implications for product cycles. Propositions 4 and 5 show that prices and market shares are relatively higher for the newer varieties and relatively lower for the older varieties when the rate of yield potential is higher compared to when this rate is lower. This implies that prices and market shares drop faster when the rate of yield potential improvement is higher. The present study assumes marginal cost is equal to zero and fixed cost is fully sunk. In such a setup, products never exit the market. Nevertheless, in a hypothetical scenario where firms would exit the market when revenues are lower than “avoidable costs” (Carlton and Perloff, 2005, page 59), a faster decrease in both price and market share results in a shorter life cycle for the product. This means, in industries with higher rates of quality improvement product cycles are shorter. This, in turn, results in smaller equilibrium number of firms. That is, more progressive industries are likely to have a smaller equilibrium number of firms, *ceteris paribus*. While this chapter attempts to provide a theoretical background on this issue, Chapter 3 uses numerical simulations to discuss the effect of rate of innovation on length of product cycles and number of equilibrium products in more depth.

2.6. Conclusion

This chapter explores the incentives for sequential innovation via the creation of new characteristics for production inputs. In addition, this study attempts to provide a basis for an analysis of Schumpeterian innovation-induced business cycles. Existing location, Chamberlinian and hybrid models do not incorporate sequential entry of production inputs that are differentiated with respect to more than two characteristics. As Benkard (2004) claims, “Models of entry for differentiated products are not yet well understood for even just a two-dimensional space.” This chapter fills a gap in the literature by developing a theoretical model that lays out the process of adding new characteristics to agricultural production inputs. Specifically, this study derives the equilibrium conditions for n varieties of seed sequentially introduced in n time periods and each of which is differentiated from other varieties with respect to one characteristic. By allowing multi-brand competition, the model overcomes the “immediate neighbors” problem, which is common in location models. The model also allows differentiated input buyers so that it is not confined to only one “representative consumer” as in Chamberlinian models. Although the model may have similarities to monopolistic competition models of analyzing product variety (i.e. location, Chamberlinian and hybrid models), it has a different perspective in that it uses the concept of “characteristics” introduced by Lancaster (1966) to explain an innovation process characterized by sequential entry of production inputs that embody new characteristics.

This model provides important insight into the incentives for innovation through the creation of new characteristics. It shows that even with a yield potential that is lower than its rivals, a seed variety still has a chance to profitably enter the market by introducing a new characteristic. Schumpeter (1939) argues that innovation-originated market power creates temporary above-normal profits, which is necessary to “induce” innovation, although this market power is doomed to be competed away as new and existing firms start imitating the monopolist’s innovation. Results of the theoretical model provide more insight into Schumpeter’s innovation theory. While Schumpeter attributes the temporary market power to new products, the current study shows that it could, in fact, be the new characteristics embodied in old or new products that create the temporary market power.

Having a setup that allows for sequential innovation leads to novel findings regarding the effect of rate of innovation on equilibrium conditions. The model shows that a higher rate of yield potential improvement results in a faster decrease in prices and market shares of older varieties in the market. This, in turn, results in shorter life cycles for the products and smaller equilibrium number of firms, *ceteris paribus*. This implies that more progressive industries (i.e. industries with higher rates of innovation) are likely to have fewer products at equilibrium. This is simply because in a highly progressive industry older products become unattractive faster than they would in industries with lower rates of innovation. This finding is novel considering the fact that locational analog and neo-Chamberlinian models find equilibrium product variety to be a function of "economies of scale", "substitutability between group and outside goods" and "share of the group in total expenditure of the economy" (Lancaster, 1990). This study determines that rate of innovation has an important role in equilibrium product variety as well. However, rate of innovation, itself, may be endogenous and determined by the other exogenous factors including the ones mentioned above.

Flexibility of the model in terms of number of production inputs in the market results in interesting findings as well. It is shown that, similar to final consumers, farm input buyers experience unbounded gains from variety. Buyers' gains from variety increase as inputs become more specific. The model also confirms that the rate of yield potential improvement and the degree of specificity (reverse adaptability) of seed varieties are important determinants of prices and market shares. The model provides a basis for more exploration through numerical simulations and empirical estimations. For example, it is observed in many industries, including the seed industry, that new higher-quality products with new features enter the market and older products exit. This chapter only briefly explores such innovation-induced product cycles. Chapter 3 incorporates sequential entry of new products that embody new characteristics and allows exit of older products when their revenues fall below avoidable costs and they are no longer viable.

2.7. Technical Limitations and Future Research

In order to focus on multiple characteristics, differentiated inputs and seed buyers, sequential innovation, and competition among differentiated products the model has made a few simplifying assumptions. While some of these assumptions are traditional in the literature, some are specific to this study and the model developed to study a seed industry. Nevertheless, it is important for the reader to be aware of the technical limitations that these assumptions may create. This section explains the technical limitations created by these assumptions.

Outside Good: It is traditional in such models to incorporate an "outside good". As Ackerberg et al. (2007, page 4186) claim, the "outside" alternative can be added to a model through an individual specific constant term without changing the preferences over products. A change in price of the outside alternative although may change the total land allocated to the crop under consideration and thereby total demand for its seed, does not change farmers' preferences over different varieties of seed. That is, although a change in price of the outside alternative (i.e. price of substitute crops) may pivot the demand curve for each variety, it does not change their relative prices and market shares. Thus, the outside alternative does not affect the competition among seed varieties of one crop. Since the model merely focuses on competition among different seed varieties of one crop, this study does not include an outside alternative in the model.

Output Price: The model allows yield to improve sequentially. Higher yield levels may result in an outward shift of the supply curve and reduction in market price of the output if demand curve is downward sloping. For the case of a small country, however, higher yield levels do not result in a reduction in market prices. This study assumes the small country case and does not endogenize output price in the model. Nevertheless, it is worth mentioning that similar to the outside alternative, output price does not change farmers' preferences over different varieties of seed. A change in output price will pivot the demand curve for each variety without changing the relative prices and market shares of the varieties. Therefore, a change in output price does not change the nature of competition among different varieties of one crop.

Land Constraint: The existence of outside land would increase the overall elasticity of demand for new characteristics as introduction of new varieties with new characteristics may encourage farmers to use the marginal land that has not been allocated to that crop previously. However, this is unlikely to be quantitatively important except in the case of drastic innovation, where a new variety significantly expands total crop area. This chapter attempts to lay out the building blocks of the model, such as differentiated input buyers, and multiple characteristics for the case of sequential, non-drastic, innovations. This is why the model assumes a constant land constraint that does not allow any increases or decreases in the total acreage of the crop. Incorporating the effect of acreage expansion is left for future studies with a focus on drastic innovations.

Entry Decision: In this model firms do not conduct a benefit-cost analysis before introducing new varieties. It is assumed that varieties will continue to be introduced until revenues minus fixed costs are no longer positive.

Firms versus Products: The model does not consider multiproduct firms. It is assumed that each firm releases only one product in the market. The model focuses on the effect of new differentiated entrants on competition. Therefore, despite the potentially insightful results, the multiproduct case is beyond the scope of this study. Nevertheless, it would be very interesting for future studies to explore pricing decisions of multiproduct firms in a setup that incorporates multiple characteristic and sequential innovation.

Symmetry: For simplicity, it is assumed that all products have the same degree of specificity (i.e. all of the varieties are assumed to be equally adaptable). Although equal adaptability is certainly not the case in reality, releasing the symmetry assumption adds significant complexity to the model. As mentioned, however, in reality various varieties of seed have different degrees of specificity. Chapter 4 considers this in by estimating the degrees of specificity for various seed varieties and exploring the effect of this variable on the varieties' market shares.

Investment decisions: The model does not incorporate the seed producers' investment decisions. In reality, however, rate of yield growth is probably a function of seed producers R&D investments. Endogenizing the yield growth rate and seed producers' R&D investments as a function of their profit levels will add more generality to the model. For example, one can explore the relationship between the seed producers' cost structure, their investment levels, and equilibrium number of seed varieties or length of product cycles. Although the theoretical model introduced in this chapter ignores the issue of endogenizing investment decisions for simplicity, this issue is explored through numerical simulations in Chapter 3.

Appendix 2.A: change in demand for old characteristics with entry of new ones

In pages 8 to 10 it was shown how interaction of land and seed characteristics determines the demand for seed varieties. This appendix shows how demand for one characteristic changes when a new characteristic is introduced.

Assume for output price of 1 and equal variety prices of 0.1 surplus (S_{ij}) in each parcel $j = 1, \cdots, 10$ is as follows:

$$Surplus\ levels(S_{ij}): \begin{array}{c} \\ 1 \\ 2 \\ 3 \\ 4 \\ 5 \\ 6 \\ 7 \\ 8 \\ 9 \\ 10 \end{array} \begin{array}{c} \begin{array}{ccc} A & B & C \end{array} \\ \begin{bmatrix} 0.13 & \boxed{0.35} & 0.29 \\ \boxed{0.19} & 0.06 & 0.09 \\ 0.15 & \boxed{0.63} & 0.23 \\ \boxed{0.38} & 0.31 & 0.35 \\ 0.24 & \boxed{0.80} & 0.13 \\ \boxed{0.86} & 0.01 & 0.43 \\ 0.76 & \boxed{0.86} & 0.79 \\ 0.42 & 0.75 & \boxed{0.75} \\ 0.61 & 0.12 & \boxed{0.88} \\ 0.11 & 0.09 & \boxed{0.40} \end{bmatrix} \end{array} ; i = A, B, C\ and\ j = 1, \cdots, 10$$

Highlighted cells show the varieties that return the highest surplus level for each parcel of land. Farmers pick the variety that provides the highest surplus (S_i) for their parcel of land.

Assume products *A*, *B*, and *C* enter the market in periods 1, 2, and 3, respectively. In period 1, variety *A* is the only available variety. Gross surplus ($P.Y_i$) created by variety *A* in parcels $j = 1, \cdots, 10$ determines maximum willingness to pay (MWTP) for variety *A* in each parcel. MWTP for variety *A* in the absence of varieties *B* and *C* (i.e. in the absence of characteristics L_1 and L_2) is presented by *MWTP(A)* in Figure A1 below. Parcels 6 and 10 have the highest and the lowest gross surplus (i.e. yield multiplied by output price) from variety *A*, 0.96 and 0.21, respectively. Therefore, shadow value of land, λ, is equal to 0.21.

In period 1, L_1 is the only available characteristic. All buyers have to buy the variety that contains characteristic L_1 for their 10 parcels of land. Nevertheless, parcels 1, 3, 5, 7, and 8 gain higher gross surplus levels from characteristic L_2. Therefore, after introduction of characteristic L_2 in period 2 these buyers switch to the variety that contains characteristic L_2. As a result, demand for variety *A* pivots from *MWTP(A)* to *MWTP(A')* in Figure 2.A.1.

In period 2, those who receive higher surplus from *C* have to buy either *A* or *B* because *C* is not available yet. With introduction of *C* in period 3 some buyers switch from *A* and *B* to *C* because *C* offers characteristic L_3 that offers a higher surplus level to parcels 8, 9, and 10. As a result, demand for variety *A* pivots from *MWTP(A')* to *MWTP(A'')*. This shows how introduction of new characteristics affects the demand for older characteristics.

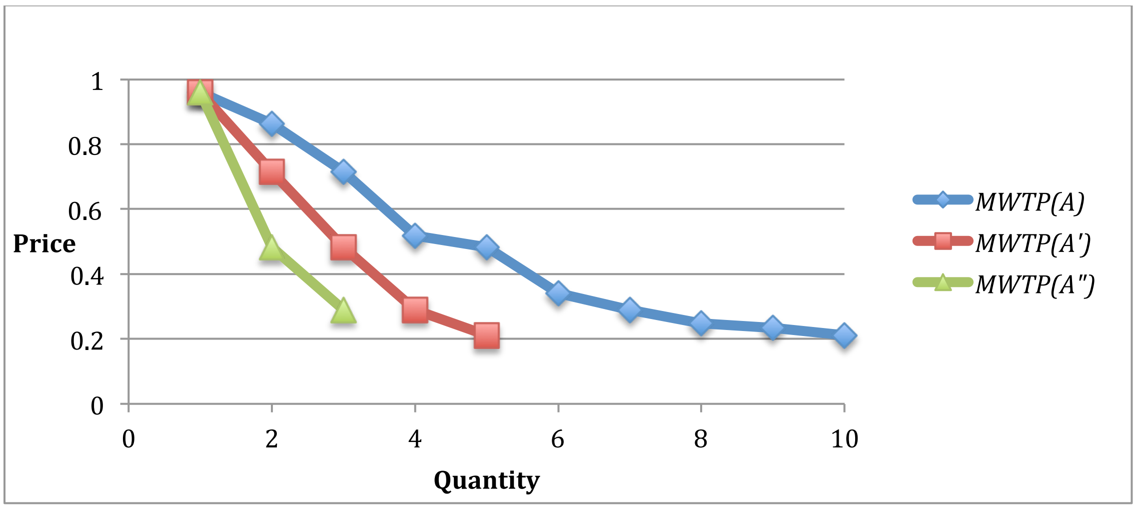


Figure 2.A.1. Change in Demand for Variety *A* with Introduction of Varieties *B* and *C*.

Appendix 2.B: Trait Bundling

This appendix explains how the conceptual framework introduced in section 2.3 can be adjusted to incorporate trait bundling. A more comprehensive discussion of trait bundling, nevertheless, is not in the scope of this paper and is left for future studies.

In Figure 2.B.1, horizontal and vertical axes measure drought-tolerance and herbicide-tolerance characteristics, respectively. Assume variety *A* embodies only the drought-resistance, variety *B* embodies only the herbicide-tolerance, and variety *AB* embodies both drought-resistance and herbicide-tolerance characteristics. Figure 2.B.1 shows the location of varieties *A* and *B* on the two-dimensional characteristics space. Variety *AB*, however, does not have a unique locus on the characteristics space. Depending on the quality of the bundled variety it could be anywhere on the thin diagonal dashed line. This refers to technical aspects of trait bundling. Yield of variety *AB*, which bundles both *A* and *B*, does not necessarily equal the simple summation of yield levels of *A* and *B* in a particular parcel of land. The bundled variety could yield more or less than the *A* or *B* (although it is unlikely that *AB* would yield less than both *A* and *B*). The profit level obtained from variety *AB*, of course, depends on its performance in the parcel of land. Isoprofit curves associated with different yield potential levels for *AB* are shown in Figure 2.B.1. The higher the bundled variety yields, the higher the isoprofit curve is.

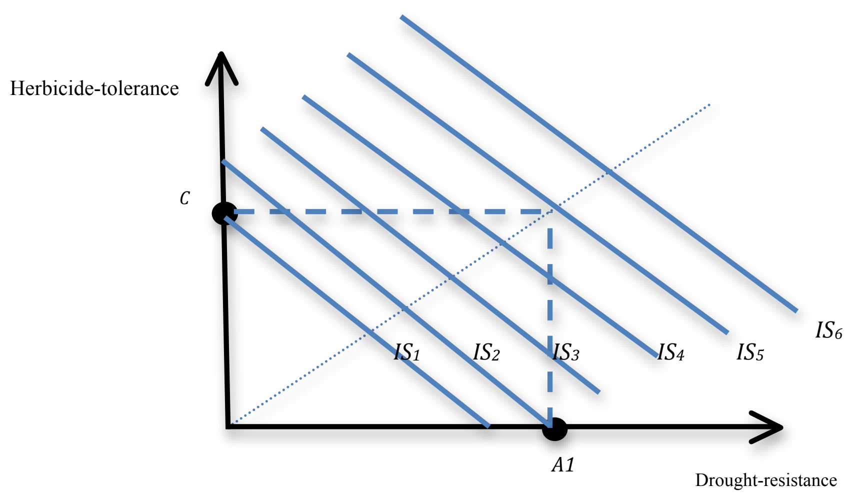


Figure 2.B.1. Trait Bundling in Two-Dimensional Characteristics Space (Adapted from Lancaster, 1979).

Appendix 2.C: Exact Demand Curve For Two Varieties With Uniform, Independently Distributed Land Characteristics

Ideally, surplus needs to be maximized for each parcel of land. The surplus maximization for each of $j = 1, \cdots, m$ equal size parcels of land from seed varieties $i = 1, \cdots, n$ can be formulated as follows:

$$Max_{X_{ij}} \sum_{j=1}^{m} \sum_{i=1}^{n} \left(P.Y_{ij} - W_i\right) X_{ij}$$

$$subject\ to\ (s.t.)\ \sum_{i=1}^{n} X_{ij} \leq \frac{\bar{X}}{m} \text{ for all } j = 1, \cdots, m$$

where $\bar{X}$ is the total amount of land in the region that is available for this crop and X_{ij} is the amount of land in parcel *j* that is allocated to variety *i*.

The Lagrangean approach is used to convert the above constrained maximization problem into an unconstrained maximization problem. The Lagrangean function corresponding to the above maximization problem is as follows:

(2.C.1) $$\mathcal{L}_S = \sum_{j=1}^{m} \sum_{i=1}^{n} \left(P.Y_{ij} - W_i\right) X_{ij} + \lambda_j \left(\frac{\bar{X}}{m} - \sum_{i=1}^{n} X_{ij}\right) \text{ for all } j$$

where λ_j, the Lagrangean multiplier, represents the opportunity cost of parcel *j*. This general maximization problem finds the variety(s) that maximizes the surplus in each parcel of land and, thus, provides an exact solution to the surplus-maximization problem.

As λ_j indicates, the above maximization problem incorporates the fact that opportunity cost of land is different for each parcel of land. This, however, makes the problem analytically difficult, if not impossible, to solve for *n* varieties. More importantly, solving this maximization problem does not determine the total demand for each variety. In order to make the problem tractable and incorporate demand for each variety, equation 2.5 is used to maximize the surplus for each variety rather than each variety in each parcel of land. Maximization of 2.5 is analytically tractable. Also, since equation 2.1 is substituted in the Lagrangean of 2.5, optimum market share of each variety, X_i, can now be easily obtained through the first order conditions of the Lagrangean.

Maximization of 2.5 translates the demand for n differentiated varieties into demand for one commodity, land, and then uses a single land constraint, as opposed to one constraint for each differentiated parcel of land, to find the demand for each variety. This means equation 2.1, which is formed on a different dimension for each variety, is assumed to have the same dimension for all varieties when substituted in equation 2.5. While equation 2.1 shows exactly how much yield decreases with increase in area for each variety in the absence of other varieties, it is a linear approximation of the decrease in yield as a result of increase in area with the existence of other differentiated competing varieties in the Lagrangean of 2.5. Thus, this simplification (i.e. translating the demand for n differentiated varieties into demand for land and using one land constraint rather than one for each parcel) results in an approximation.[19]

This appendix derives the exact demand curve for the simple case of only two varieties with independent land characteristics and compares the results to the linear approximate demand curves that are obtained from the maximization of 2.5.

For i.i.d. land characteristics the maximization of 2.5 provides an approximation. Figure 2.C.1 shows the source of this approximation for a simple case of only two varieties. Panel i of Figure 2.C.1 is similar to Figure 2.2. This panel shows the allocation of parcels of land between two varieties that correspond to two independent characteristics and have the same yield potential ($\hat{y}_2 = \hat{y}_1$). Each dot on the Figure represents a parcel of land. The locus of each dot represents the yield level that the parcel can obtain from varieties 1 and 2. Panel ii of Figure 2.C.1 depicts the demand curve for variety 1 assuming varieties 1 and 2 have the same degree of specificity ($\mu_1 = \mu_2 = \mu$) and output price P is equal to 1.

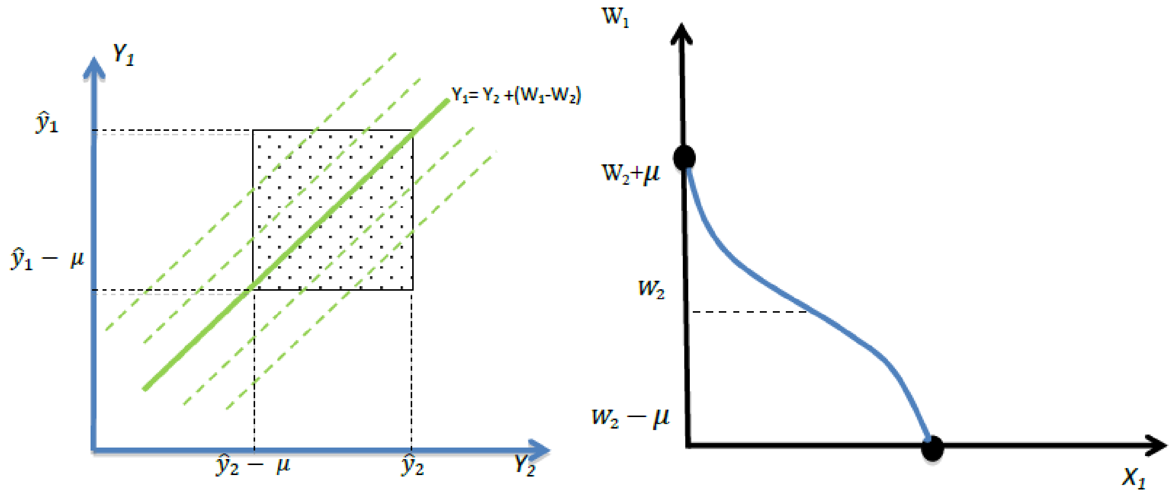
The green price line in Panel i is the locus of the parcels of land that obtain the same level of surplus from either variety 1 or variety 2. The equation for this line is as follows:

$Y_1 = W_1 - W_2 + Y_2$

where W_1 and W_2 determine the intercept, and slope is equal to 1.

[19] While this study focuses on the case of uniform i.i.d. land characteristics, it may be interesting for future studies to explore the magnitude of the approximation in case of other distributions such as Normal and correlated characteristics.

As shown in panel *i*, as W_1 increases while W_2 is fixed, the price line shifts up in a parallel fashion and some parcels of land switch from variety 1 to variety 2. However, notice that as the green curve moves higher and higher, fewer and fewer parcels of land switch to variety 2. This is because the land characteristics that varieties 1 and 2 correspond to are independent and, thus, parcels of land are spread over the space in between Y_1 and Y_2 axes with the same density. Similarly, each time price of variety 1 is decreased, fewer and fewer parcels switch to this variety. This relationship between change in price of a variety and number of parcels that switch implies a non-linear demand curve for the variety. This demand curve is illustrated in Panel *ii* of Figure 2.C.1.



Panel i- Allocation of Parcels of Land to Two Varieties *Panel ii-Demand for Variety 1*

Figure 2.C.1. Exact Non-Linear Demand for the Case of Independent Land Characteristics.

In order to find the exact demand curve for variety 1 in the presence of variety 2 one needs to measure the market share of variety 1 in Panel *i* of Figure 2.C.1. As shown in Section 2.4.1, yield of variety *i* in parcel *j* can is obtained as follows:

$$[\hat{y}_i]_{m\times n} - [\theta_{ji}]_{m\times n}\times[\mu_{ii}]_{n\times n}\times[L_{ii}]_{n\times n} = [Y_{ji}]_{m\times n}$$

where $[\hat{y}_i]_{m\times n}$ represents the yield potential levels of varieties $i = 1, \dots, n$, $[\theta_{ji}]_{m\times n}$ the levels of *n* independent land characteristics in *j=1,…,m* parcels of land, $[\mu_{ii}]_{n\times n}$ the response of the yield of variety *i* as a result of one unit change in the corresponding land characteristics, $[L_{ii}]_{n\times n}$ the seed characteristics in varieties $i = 1, \dots, n$, and $[Y_{ji}]_{m \times n}$ the yield levels of varieties $i = 1, \dots, n$ at parcels $j=1,\dots,m$. Since land characteristics are i.i.d. uniform variables ($\theta_j \sim u(0,1)$) and seed characteristics do not have a distribution, the resulting yield levels are i.i.d uniform variables with the following distribution:

$$Y_i \sim u(\hat{y}_i - \mu_i, \hat{y}_i)$$

That is, yield of variety i is uniformly distributed between $\hat{y}_i - \mu_i$ and $\hat{y}_i$ over the range of the parcels of land. Therefore, Y_1 is uniformly distributed between $\hat{y}_1$ and $\hat{y}_1 - \mu$. Similarly, Y_2 is uniformly distributed between $\hat{y}_2$ and $\hat{y}_2 - \mu$. Putting random plots of Y_1 and Y_2 on separate axes, total area of the rectangle is μ^2 with probability density function of $1/\mu$ throughout.

In the case when only one variety exists the use of the variety will be determined by the level of Y_1 and W_1. The proportion of land where $Y_1 \geq W_1$ will determine the quantity of variety demanded. Given the uniform distribution of the land characteristic the single firm selling the variety will face a demand curve with a price intercept of $\hat{y}_1$ and slope of $-\mu$. It is assumed that W_1 is low enough that all canola farmers buy the seed.

When there are two varieties in the market the demand for each variety is dependent on its own yield, the other variety's yield, and both variety prices. When $W_i \leq \hat{y}_i - \mu$, $i = 1, 2$ it is possible to derive an exact demand curve for each variety. In this case farmers must chose which variety to use on each parcel of land. The locus of the land parcels where famers are indifferent between the varieties is given by $Y_1 - W_1 = Y_2 - W_2$. In the (Y_2, Y_1) space the equation for the line of indifference is $Y_1 = W_1 - W_2 - Y_2$. For all land parcels above the line the farmers will earn higher surplus from purchasing variety 1 and parcels below this line of indifference the growers will purchase variety 2. Given the uniform density of the square, the proportion of the area above the line represents the demand for X_1. By dividing the area of variety 1's market share to the total area of the rectangle, which is μ^2, demand for variety 1 is obtained as follows:

$$\text{(2.C.2)} \qquad \begin{cases} X_1 = 0 \; for \; (\mu - W_1 + W_2) < 0 \\ X_1 = \frac{(\mu - W_1 + W_2)^2}{2\mu^2} \; for \; W_1 \geq W_2 \; and \; (\mu - W_1 + W_2) \geq 0 \\ X_1 = 1 - \frac{(\mu - W_2 + W_1)^2}{2\mu^2} \; for \; W_1 \leq W_2 \; and \; (\mu - W_2 + W_1) \geq 0 \\ X_1 = 1 \; for \; (\mu - W_2 + W_1) < 0 \end{cases}$$

As shown in equation 2.C.2, the exact demand curve consists of two quadratic functions that connect together where W_1 is equal to W_2. The second derivative of the demand curve is positive for $W_1 \geq W_2$ and negative for $W_1 \leq W_2$. The average slope of this exact demand curve is - 2 μ. Also, by relaxing the $\hat{y}_1 = \hat{y}_2$ assumption, the price intercept of the exact demand curve for variety 1 is $W_2 + \mu + \hat{y}_1 - \hat{y}_2$. Figure 2.C.2 depicts the effect of an increase in price of variety 2 (from W_2 to W_2') and a decrease in price of variety 2 (from W_2 to W_2'') on demand for variety 1.

The exact demand equation presented in equation 2.C.2 is difficult to generalize to more than two varieties.[20] However, the maximization of 2.5 results in an approximate demand curve that is depicted by the dashed downward sloping curve in Figure 2.C.2.

The equation for the dashed downward sloping curve (i.e. the approximate demand curve) is as follows:

(2.C.3) $$W_1 = W_2 + \mu - (2\mu)X_1 \quad \text{for } \hat{y}_2 = \hat{y}_1$$

By relaxing the $\hat{y}_2 = \hat{y}_1$ assumption, equation for the approximate demand curve becomes as follows:

(2.C.4) $$W_1 = \hat{y}_1 - \hat{y}_2 + W_2 + \mu - (2\mu)X_1$$

It is easy to see that the approximate demand curve has the same intercept and slope as the exact demand curve in equation 2.C.2. The approximate demand curve also crosses the exact demand curve where W_1 is equal to W_2.[21]

[20] With three varieties similar geometric approach can be employed using the volume within a three dimensional probability density cube to derive an exact demand curve.

[21] One could change the distribution of land characteristics in Panel *i* of Figure 2.C.1 to show that for any symmetric distribution (e.g. Normal) the exact and approximate demand curves cross where W_1 is equal to W_2.

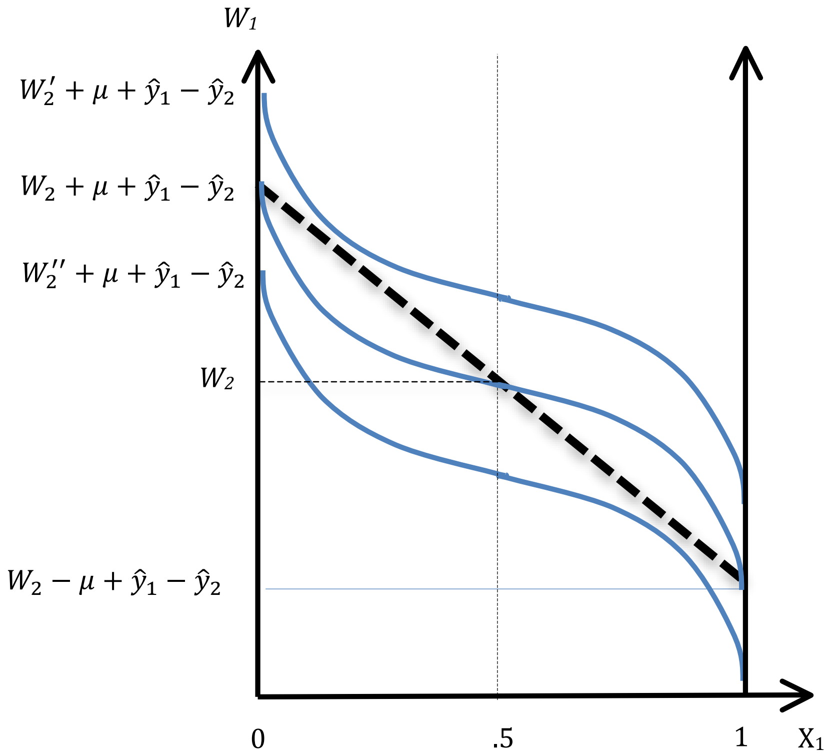


Figure 2.C.2. Exact Non-Linear Demand for the Case of Independent Land Characteristics.

It is shown in equation 2.8-a that the demand curves that are obtained from the first order conditions of equation 2.5 are the same as equation 2.C.4 for variety 1. Therefore, for the case of i.i.d uniform land characteristics, use of maximization of 2.5 results in a linear approximation of the non-linear demand curves. As it is shown for the case of two varieties, the resulting approximate demand curves have the same intercept and slope as the exact demand curve. Therefore, the approximate demand curves can be used in the seed producers' profit maximization problem to find equilibrium price, quantity, and profit levels. Also, since the approximate demand curves are a function of yield potential and degree of specificity of the varieties, they can be used to explore the effect of changes in yield potential and degree of specificity on prices and other equilibrium conditions. Comparing the demand curves that result from the first order conditions of equation 2.5 and the exact demand curve in equation 2.C.2, it is easy to see that the approximation simplifies the demand relationships significantly while keeping the critical elements (i.e. the average slope and the intercept) intact. This simplicity becomes particularly important and very useful when equilibrium conditions are found for the case of *n* varieties.

Therefore, this study uses the maximization of 2.5 that results in linear approximation of demand curves that are non-linear. The maximization of 2.5 approximates how many parcels of land must be allocated to each variety in order to ensure that shadow value of the last parcel allocated to each variety is equal to the shadow value of the last parcel allocated to all the other varieties.

It is worth noting that as land characteristics become more negatively correlated, the dots in Panel *i* of Figure 2.C.1 become more concentrated around a diagonal line perpendicular to the price line. As a results, the gap between the approximate and exact demand curves shrinks. In fact, with perfectly negatively correlated land characteristics, the linear demand curve is no longer an approximation, but the exact demand curve. The implications are interesting. In the mid part, the non-linear demand curve is more elastic than the linear demand curve. This implies that, in the mid part of the demand curve, as substitutability decreases (i.e. as correlation coefficient between two land characteristics approaches negative one), price increases. This is consistent with economic theory.

Chapter 3: Numerical Simulations

3.1. Introduction

Chapter 2 introduced a theoretical model that explains the incentives to create new characteristics for new production inputs. This model incorporates competition among n production inputs that embody differentiating characteristics. In this chapter, older production inputs are allowed to leave the market when their market share falls to the point where they are no longer viable. Some properties of the model were shown in propositions and algebraic proofs in Chapter 2. In this chapter, numerical simulations are performed to further investigate the validity of these propositions, and provide more insight into dynamic aspects of the model such as product cycles.

While Chapter 2 assumes the rate of yield potential growth is exogenous, this chapter endogenizes this rate as a function of the seed producers' investment levels. Investment levels, in turn, are chosen such that firms' future profits are maximized. Optimum investment levels are found for various levels of exogenous variables and several cost structures. Results of numerical simulations imply that the degree of heterogeneity of seed buyers (i.e. degree of specificity of seed varieties), breeders' investment productivity, which also represents firms' economies of size, and fixed overhead or maintenance cost of keeping a variety in the market are important determinants of the optimum investment level and other equilibrium conditions such as price levels and number of products.

The remainder of this chapter is organized as follows: Section 3.2 discusses some evidence of sequential innovation and product cycles in the seed industry and then presents some preliminary numerical simulations on the effect of rate of yield potential growth and degree of specificity on equilibrium steady states conditions. In section 3.3 the rate of yield potential growth is endogenized as a function of the seed producers' investment levels. Numerical simulations are performed to find the effect of exogenous variables on equilibrium steady states conditions under the endogenous investment assumption. Last, section 3.4 presents the conclusion of this chapter.

3.2. Numerical Simulations and Equilibrium Steady States

In this section, numerical simulations are performed to provide a better understanding of the theoretical model. The theoretical model presented in the previous chapter is used to analyze

Schumpeterian product cycles, pricing strategies, and evolution path of industries characterized by sequential innovation.

Product cycles: A drastic innovation (i.e. hybrid technology) is introduced through variety 1 for the first time. Varieties 1 to *n* are sequentially introduced to the market. The model incorporates sequential innovation through two circuits: product improvement and new characteristics. This is consistent with the reality of many seed industries. The following table, for example, shows the evidence of vertical and horizontal differentiation for Canadian wheat varieties in 1972-2006 period. The third column of Table 3.1 shows the increase in yield potential of wheat varieties. The third to last rows of Table 3.1 show the traits that have been added to wheat varieties from 1972 to 2006.

Table 3. 1. Yield Potential and Traits Added to Canadian Wheat Varieties 1972-2006.

Year	Name	Yield Potential % of Manitou	Resistant to								
1972	Neepawa	104	Stem Rust	Leaf Rust	Loose Smut	Root Rot					
1986	Katepwa	107	Stem Rust	Leaf Rust	Loose Smut	Root Rot	Bunt				
1997	AC Barrie	121	Stem Rust	Leaf Rust	Loose Smut	Root Rot	Bunt	Leaf Spot	Sprouting		
1998	AC Elsa	121	Stem Rust	Leaf Rust	Loose Smut	Root Rot	Bunt	Leaf Spot	Sprouting	FHB	
2006	AC Superb	132	Stem Rust	Leaf Rust	Loose Smut	Root Rot	Bunt	Leaf Spot	Sprouting	FHB	Head Awnednes

Source: Saskatchewan Seed Growers Association (Various years).

As new and higher quality varieties are introduced to the market, market share of the older varieties drops. Older varieties, including the original innovation, will eventually be forced out of the market when they are no longer profitable. However, similar to product introduction, product elimination occurs in a sequential manner. As a result, each product has a life cycle. This sequential entry and exit pattern is similar to what is observed in many seed industries. Following figure shows this pattern for four canola varieties in Saskatchewan (2008-2012). It is shown, for example, how market share of 5020 decreases as 5440 and 45H28 become adopted. Similarly, 5440 continues its disadoption process when L150 is introduced.

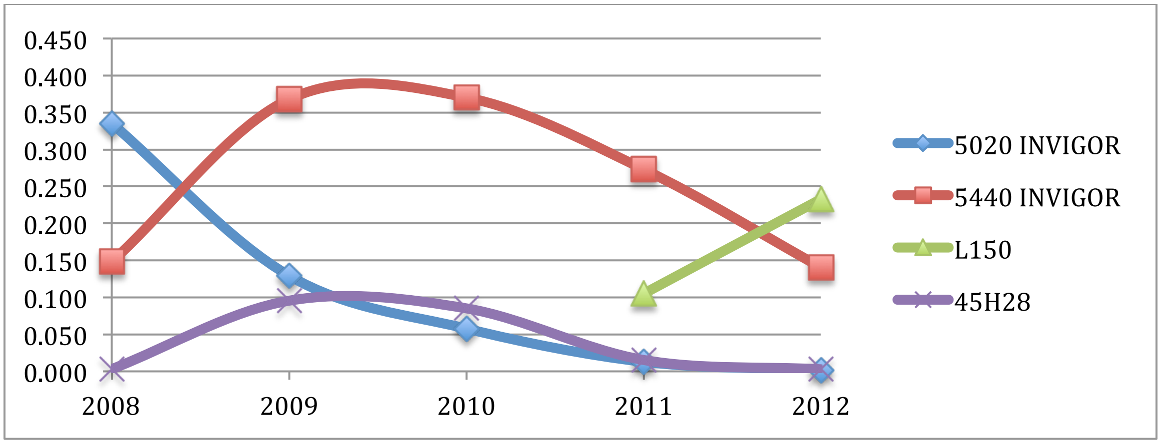


Figure 3. 1. Adoption Rate of Four Canola Varieties in Saskatchewan (2008-2012).
Source: Saskatchewan Crop Insurance Corporation

There has been a growing attention to sequential innovation in economics literature. Chapter 1 procides a short review of studies performed by Scotchmer, O'Donoghue and others. Grossman and Helpman (1991a) argue "almost every product exists on a *quality ladder*, with variants below, that may already have become obsolete, and others above, that have yet to be discovered." They criticize the literature on patent races introduced by Loury (1979), Dasgupta and Stiglitz (1980), and Lee and Wilde (1980) for having a "one-shot framework [that] fails to capture an essential aspect of quality competition." Grossman and Helpman (1991a) refer to the works of Segerstrom et al. (1990) and Aghion and Howitt (1990) as "the beginning of a theory of repeated quality innovations." In what follows sequential innovation is incorporated in the theoretical model presented in Chapter 2. This is to provide some insights into the relationship between quality improvement and product cycles, pricing strategies, and evolution path of industries characterized by sequential innovation.

To incorporate sequential innovation through quality improvement, it is assumed that yield potential of new varieties improves over time with rate of k such that:

(3.1) $$\hat{y}_t = \hat{y}_{t-1} + k$$

where t represents time, $\hat{y}$ yield potential, and k rate of yield potential growth.

To incorporate addition of new characteristics, it is assumed that each new variety has a distinguishing characteristic that differentiates it from other varieties. Thus, a new product not only features a new characteristic, but also has a higher yield potential.

The market share of a variety at time *t*, obtained in the previous chapter, is as follows:

(3.2) $$X_t = \frac{1}{n}\left(1 + \frac{(n-1)\sum_{i=1}^{n}(\hat{y}_t - \hat{y}_i)}{(2n-1)\mu}\right) \forall\, 1 \leq t \leq n \; and \; t \neq i.$$

By substituting equation 3.1 into equation 3.2 it can be written as follows:

(3.3) $$X_t = \frac{1}{n}\left(1 + \frac{(n-1)(nt-\sum_{i=1}^{n} i)k}{(2n-1)\mu}\right) \; \forall\, 1 \leq t \leq n \; and \; t \neq i.$$

where X_t is the market share of the variety introduced at time *t* and *k* is the rate of yield potential growth rate. Table 3.2 presents the market shares of 10 sequentially introduced varieties, assuming $\mu = 0.5$ and yield growth rate *k*=0.02. It is assumed that a variety is eliminated from the market when its market share drops under 5 percent. This percentage is an arbitrary number only to somehow incorporate the maintenance cost of keeping a variety in the market. This is modified to a zero profit condition and discussed in depth in the next section.

After time 7, with introduction of each variety, one variety leaves the market and the number of products in the market remains constant at 8. This is an Equilibrium Steady State (ESS) with 8 products in the market. The interesting feature of the ESS is the set of equilibrium market shares. The ESS is characterized by a vector of market shares, *X*=[0.06, 0.08, 0.10, 0.12, 0.13, 0.15, 0.17, 0.19], that represents the market shares for the lowest to the highest quality variety in the ESS. This is shown in the highlighted column in Table 3.2. Products sequentially enter and leave the market but the vector of equilibrium market shares does not change; the highest and lowest quality products always obtain 19 and 6 percent market share, respectively. Consistent with proposition 3 in Chapter 2, there is higher market share for new varieties because they have higher yield potential.

The market share of each variety decreases over time as new and higher quality varieties are introduced. In the ESS each variety will obtain 19 percent market share upon entrance; but this market share gradually drops to 6 percent as new and higher quality varieties enter the market.

This is shown in the highlighted row in Table 3.2. In the neighbourhood of equilibrium, a new (and highest quality) variety always obtains the largest market share upon introduction and then loses its market share as newer and higher quality products are introduced. This reduction in market share continues until the variety is completely out of the market.[22]

Table 3. 1. Distribution of Market Shares for *k*=0.02 and μ = 0.5.

Variety \ Time	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1	1	0.49	0.32	0.22	0.16	0.12	0.09	0.06	-	-	-	-	-	-	-	-
2		0.51	0.33	0.24	0.18	0.14	0.11	0.08	0.06	-	-	-	-	-	-	-
3			0.35	0.26	0.20	0.16	0.12	0.10	0.08	0.06	-	-	-	-	-	-
4				0.28	0.22	0.18	0.14	0.12	0.10	0.08	0.06	-	-	-	-	-
5					0.24	0.19	0.16	0.13	0.12	0.10	0.08	0.06	-	-	-	-
6						0.21	0.18	0.15	0.13	0.12	0.10	0.08	0.06	-	-	-
7							0.20	0.17	0.15	0.13	0.12	0.10	0.08	0.06	-	-
8								0.19	0.17	0.15	0.13	0.12	0.10	0.08	0.06	-
9									0.19	0.17	0.15	0.13	0.12	0.10	0.08	0.06
10										0.19	0.17	0.15	0.13	0.12	0.10	0.08
11											0.19	0.17	0.15	0.13	0.12	0.10
12												0.19	0.17	0.15	0.13	0.12
13													0.19	0.17	0.15	0.13
14														0.19	0.17	0.15
15															0.19	0.17
16																0.19
HHI																**0.13**

Source: Author's estimations.

[22] Market shares in product cycles may seem counter intuitive as each variety starts off at the peak of its adoption curve upon entrance and then it goes through disadoption as newer varieties enter the market. This is inconsistent with S-shaped adoption curves described in many studies, particularly those of Rogers (1983) and Griliches (1957). The S-shaped adoption curves are based on the assumption that adoption occurs as adopters form expectations about the benefits of a new innovation. The literature on disadotion, however, is sparse (Dinar and Yaron, 1992). As a new variety is being adopted, an older variety must become disadopted (Dinar and Yaron, 1992).
The current study focuses on the disadoption of older varieties as a result of entry of new varieties. Since this study solely focuses on the disadoption part of the adoption curves, it is assumed that buyers have perfect information and fully form their expectations about a new variety upon its entry so a new variety always starts at the peak of its adoption curve. Nevertheless, factors that form the adoption part of a product cycle do not seem to be the same as those that form the disadoption part of the product cycle. While expected profit is the main factor that forms the adoption part of a product cycle (Griliches, 1957), technological substitution is mainly responsible for disadoption (Fisher and Pry, 1971; Rogers, 1983; Cameron and Metcalfe, 1987).

Numerical simulations help find the factors that determine a product's life cycle. The number of products and vector of equilibrium market shares are a function of the yield growth rate *k* and the degree of specificity μ.

The literature on optimal variety is very rich on the relationship between degree of heterogeneity of consumers, which is a parallel concept to the degree of specificity in this study, and prices, number of products, etc. The relationship between quality improvement, which is referred to as yield growth rate in this study, and equilibrium conditions may not have been explored as intensively. Chapter 1 and the beginning of this section provided a review of the literature on "the theory of repeated quality improvements" (Grossman and Helpman (1991a); Segerstrom et al. (1990); Aghion and Howitt (1990)). In addition to this literature, DeBrock (1985) highlights the importance of properly incorporating competition when modelling R&D and patent life. DeBrock 1985 argues that "Clearly, rivalry has effects on the R & D process; just as clearly, the R & D process affects rivalry." As well, Dasgupta and Stiglitz (1980) argue that market structure needs to be considered as an endogenous variable.

The literature, although posing intriguing questions, does not explicitly discuss differentiated products. This provides an incentive to use the framework presented in Chapter 2, which incorporates differentiated seed varieties, to study the relationship between yield potential growth rate and equilibrium conditions.

To illustrate the effect of a higher yield potential growth rate on product cycles, Table 3.3 presents the simulated market shares with a higher yield growth rate compared to that of Table 3.2. Simulations of Table 3.3 are performed assuming $\mu = 0.5$, and yield growth rate *k=0.05*, which is higher than *k=0.02* in Table 3.2.

Comparing varieties life cycles in Table 3.2 and Table 3.3 shows that when yield growth rate increases from *k*=0.02 to *k*=0.05, life cycles shorten. With *k*=0.02, varieties stay in the market for 8 periods, whereas with *k*=0.05 they stay in the market for 6 periods. The faster the yield potential of new varieties improves, the faster older varieties have to leave the market and, therefore, their life cycle is shorter. A higher rate of yield growth rate and the resulting shorter cycles also lead to fewer varieties in the market.

This insight is comparable to the result of Dasgupta and Stiglitz (1980) study. They argue that a monopolist may use "fast research" as a means of preventing potential entry to the R&D

market (Dasgupta and Stiglitz, 1980). If this is the case, then one could also arguably claim that faster research, in the R&D market, results in fewer number of products in the product market, which is what the simulations in this chapter show.

Table 3. 2. Distribution of Market Shares for *k*=0.05 and μ = 0.5.

Time / Variety	1	2	3	4	5	6	7	8
1	1	0.48	0.29	0.19	0.11	0.05	-	-
2		0.52	0.33	0.23	0.16	0.10	0.05	-
3			0.37	0.27	0.20	0.14	0.10	0.05
4				0.31	0.24	0.19	0.14	0.10
5					0.29	0.23	0.19	0.14
6						0.28	0.23	0.19
7							0.28	0.23
8								0.28
HHI								**0.20**

Source: Author's estimations.

As shown in the last rows of tables 3.2 and 3.3, Herfindahl–Hirschman Index (HHI) of market concentration increases from 0.13 to 0.20 as the rate of yield potential growth increases from 0.02 to 0.05.

A lower rate of yield potential improvement has the opposite effect of what is described above. With no yield potential improvement (i.e. *k=0*), however, the sequential exit no longer occurs. In such a case, varieties equally share the market and are equally priced. With entry of each new variety, market share and price of the all varieties drops. In case of no yield potential improvement entry stops when there is no above normal profit left in the market.

Another factor affecting product cycles is the degree of specificity μ. This represents how fast yield potential drops as area under cultivation of a variety increases. As the degree of specificity μ increases, one would expect more varieties to exist in each period of time. To avoid repetition, an in-depth discussion of the effect of the degree of specificity on market shares is left to section 3.3.3.

Figure 3.2 provides an illustration of the ESS market shares presented in tables 3.2 and 3.3. The blue curve is the baseline with *k*=0.02 and μ = 0.5. The red curve represents the disadoption associated with a higher rate of yield potential growth of *k*=0.05 compared to *k*=0.02.

Comparison of the blue and the red curves indicates that a higher rate of yield potential growth results in a shorter but steeper disadoption curve. This, in turn, implies fewer products with shorter life cycles.

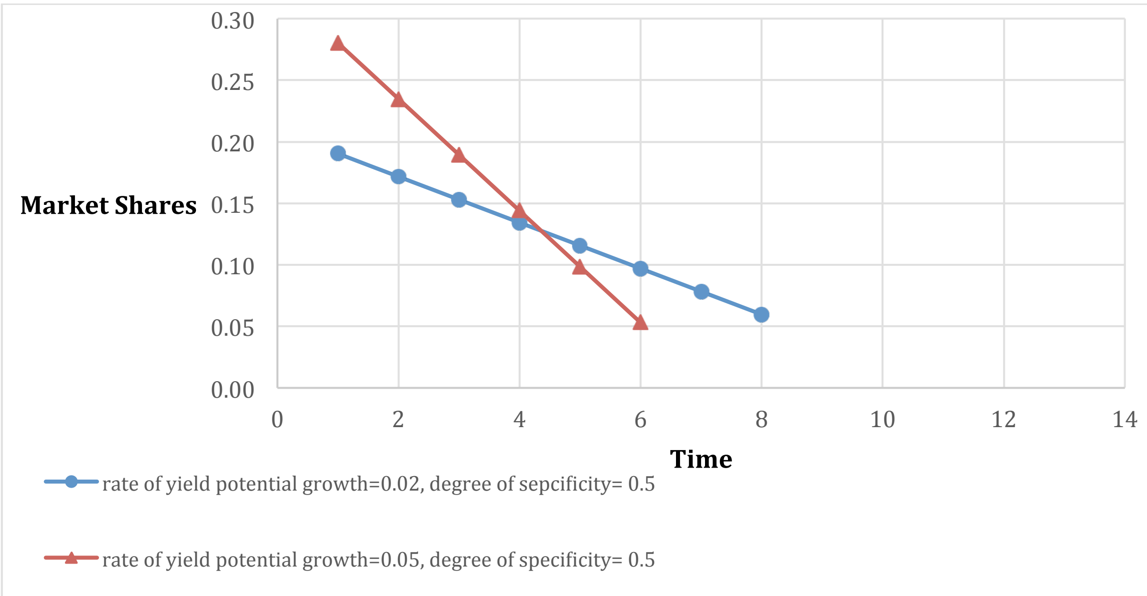


Figure 3. 2. Effect of Rate of Yield Potential Growth and Degree of Specificity on Length of Product Cycles.

Price structure: Price of a new variety is a function of its own yield potential and yield potential of its rivals. It is also a function of the degree of specificity μ and number of existing varieties n. This is shown in the following equation from previous chapter:

(3.4) $$W_t = \frac{\sum_{i=1}^{n}(\hat{y}_t - \hat{y}_i)}{2n-1} + \frac{\mu}{n-1} \qquad \forall\, 1 \le t \le n \; and \; t \ne i.$$

Assuming yield potential improves over time with the constant rate of k as in equation 3.1, the price of a variety introduced at time t can be formulated as follows:

(3.5) $$W_t = \frac{(nt - \sum_{i=1}^{n} i)k}{(2n-1)} + \frac{\mu}{n-1} \quad \forall\, 1 \le t \le n \; and \; t \ne i.$$

Table 3.5 presents the simulated prices for 10 varieties released sequentially into the market place. Similar to the simulated market shares presented in table 3.2, the degree of specificity μ is assumed to be 0.5 and yield growth rate is assumed to be k=0.02.

As shown in table 3.4, variety 1 (i.e. the original innovation) follows a declining price path as new and higher quality varieties enter the market. Newer products follow a declining price path as well. As the number of varieties increases, competition gets fiercer and prices fall.

Table 3. 3. Distribution of Prices for Linear Yield Growth Rates of k=0.02, and μ = 0.5.

Variety \ Time	1	2	3	4	5	6	7	8	9	10
1	1	0.49	0.24	0.15	0.10	0.07	0.05	0.03	-	-
2		0.51	0.25	0.16	0.11	0.08	0.06	0.04	0.03	-
3			0.26	0.17	0.13	0.09	0.07	0.06	0.04	0.03
4				0.18	0.14	0.11	0.08	0.07	0.06	0.04
5					0.15	0.12	0.09	0.08	0.07	0.06
6						0.13	0.10	0.09	0.08	0.07
7							0.12	0.10	0.09	0.08
8								0.11	0.10	0.09
9									0.11	0.10
10										0.11

Source: Author's estimations.

With the introduction of variety 9, variety 1 leaves the market. After time 8, with the introduction of each variety, one variety leaves the market and the number of products in the market remains constant at 8. This is an ESS with 8 products in the market. The interesting point of this equilibrium is the vector of equilibrium prices. The ESS is characterized by a vector of prices, W=[0.03, 0.04, 0.06, 0.07, 0.08, 0.09, 0.10, 0.11]. Products sequentially enter and leave the market but the vector of equilibrium prices does not change; the highest and lowest quality products are always priced at 0.11 and 0.03, respectively.

Both the number of equilibrium products and the vector of ESS prices are functions of the yield growth rate k and the degree of specificity μ. Table 3.5 presents the simulated prices for 8 varieties, assuming $\mu = 0.5$ and yield growth rate k=0.05.

Comparing tables 3.4 and 3.5 shows that a higher yield growth rate (k=0.05 compared to k=0.02) results in fewer products in the ESS. Also, on average prices are higher with yield growth rate of 0.05 compared to 0.02, which is consistent with proposition 5 of Chapter 2 regarding the effect of rate of yield potential improvement on prices. A higher yield growth rate enables the seed producers to price their varieties higher. This occurs through two mechanisms, direct and indirect. In the direct mechanism, a variety can be priced higher because it offers higher quality. In the indirect mechanism, a higher yield growth rate results in a smaller number of varieties and that provides the seed producers with more market power so they can price their varieties higher.

Table 3. 4. Distribution of Prices for $\mu = 0.5$, and *k=0.05*.

Time / Variety	1	2	3	4	5	6	7	8
1	1	0.48	0.22	0.12	0.07	0.03	-	-
2		0.52	0.25	0.15	0.10	0.06	0.03	-
3			0.28	0.18	0.13	0.09	0.06	0.03
4				0.21	0.15	0.11	0.09	0.06
5					0.18	0.14	0.11	0.09
6						0.17	0.14	0.11
7							0.17	0.14
8								0.17

Source: Author's estimations.

Figure 3.3 provides an illustration of the ESS prices presented in tables 3.5 to 3.7. The blue curve is the baseline with *k*=0.02 and μ = 0.5. The red curve represents the price path associated with a higher rate of yield potential growth of *k*=0.05 compared to *k*=0.02. Comparison of the blue and the red curves indicates that with a higher rate of yield potential growth although varieties start with significantly higher prices, they go through a much faster decline in their prices as the disadoption process occurs faster.

Both the number of equilibrium products and the vector of ESS prices are also functions of the degree of specificity μ. To avoid repetition, an in-depth discussion of the effect of the degree of specificity on prices is left to section 3.3.3.

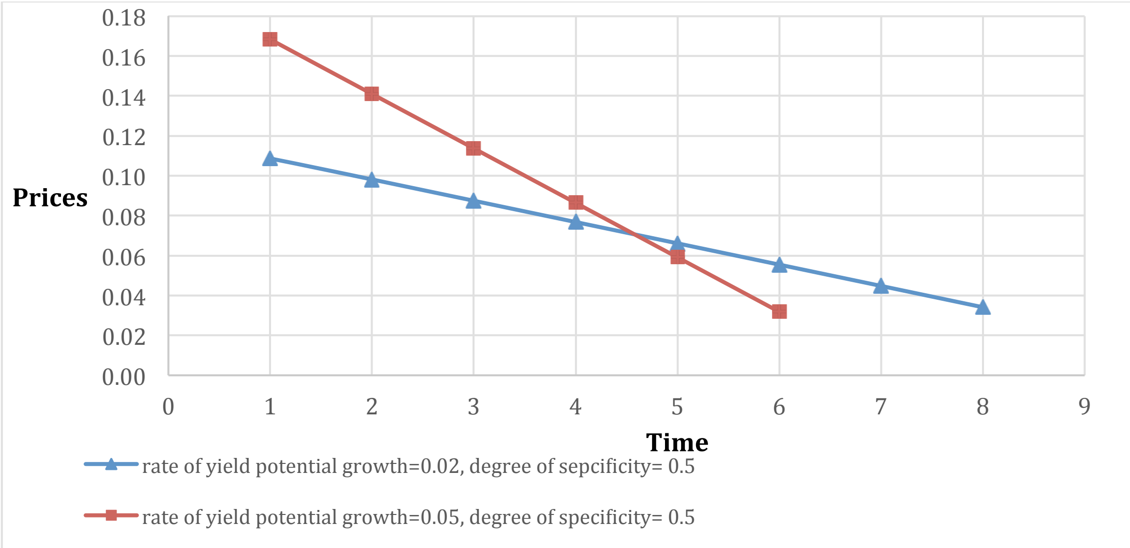


Figure 3. 3. Effect of Rate of Yield Potential Growth and Degree of Specificity on Prices throughout a Product's Life Cycle.

Equilibrium Steady States and Neighbourhood of Equilibrium: As shown in tables 3.2 to 3.5, number of varieties in the market is not random. Varieties are sequentially introduced into the market until their number reaches equilibrium. The number of varieties, a vector of prices and a vector of market shares characterize the ESS. The highest quality product will always have a specific price and market share. This holds for second highest quality variety, third highest quality variety, and so on. Since new products enter the equilibrium and old products exit, we call this a neighbourhood of equilibrium; the neighbourhood of equilibrium is constantly evolving.

Number of varieties, vector of prices, and vector of market shares in the ESS are a function of market characteristics such as yield growth rate and degree of specificity. For example, as shown in Table 3.2 and Table 3.5, k=0.02 and μ = 0.5 result in a neighbourhood of equilibrium with n=8, W=[0.03, 0.04, 0.06, 0.07, 0.08, 0.09, 0.10, 0.11], and X=[0.06, 0.08, 0.10, 0.12, 0.13, 0.15, 0.17, 0.19]. A higher yield growth rate results in an ESS with a smaller n, higher prices and larger market shares. A higher degree of specificity results in an ESS with a larger n, higher prices and smaller market shares.

The concept of ESS introduced in this chapter is similar to the concept of neighbourhood of equilibrium introduced by Schumpeter (1939) in the sense that in both concepts as market deviates from the old equilibrium it moves towards a new equilibrium. However, there is a difference between neighbourhood of equilibrium and the concept of "equilibrium" used in other hybrid models and the representative consumer models. In these models, equilibrium is described with a certain number of equally substitutable products. These products do not change over time. In fact, there is no place for time and, therefore, evolution of the industry in these models. The current model, however, allows for evolution and change in the industry through sequential innovation. In the current model, although the industry reaches equilibrium, products change over time. That is, older products will be forced out of the market as new products are introduced into the market. This evolution (i.e. elimination of older products and introduction of newer products), however, always occurs within the neighbourhood of equilibrium.

3.3. Endogenized Rate of Yield Growth Potential

In the theoretical model presented in Chapter 2 it is assumed that the rate of yield potential growth is exogenous. The numerical simulations presented in the previous section assume an exogenous rate of yield potential growth as well. Rate of yield potential growth is determined by the amount of R&D investment. And as noted by Grossman and Helpman (1991), "research responds to profit incentives." In this section, the rate of yield potential growth is endogenized as a function of the amount of initial investment that firms make. The firms' investment level is assumed to be a function of expected future profits. The rate of yield potential growth, in turn, determines the prices, market shares, number of firms and, thereby, the profit levels. Thus, the goal is to find the investment level that maximizes the profit obtained from each variety.

To find the profit-maximizing investment level and the subsequent rate of yield potential growth, prices, market shares, and number of firms, the following maximization problem is set up.

(3.6-a) $\text{Max}_I\ \pi_i = \sum_{t=1}^{n}(W_t X_t - FMC_t) - I \qquad ;\ 1 \leq i \leq n.$

Subject to the constraints:

(3.6-b) $X_t = \frac{1}{n}\left(1 + \frac{(n-1)(nt - \sum_{i=1}^{n} i)k}{(2n-1)\mu}\right) \qquad ;\ 1 \leq t \leq n.$

(3.6-c) $W_t = \frac{(nt - \sum_{i=1}^{n} i)k}{(2n-1)} + \frac{\mu}{n-1}$; $1 \leq t \leq n$.

(3.6-d) $k = I^{\alpha}$; $0 < \alpha$

(3.6-e) $W_t X_t > FMC_t$; $1 \leq t \leq n$

(3.6-f) $W_t X_t < FMC_t$; $t \geq n + 1$

where π_i is the profit that each variety *i=1, 2, 3, …, n* obtains throughout its life cycle, *t=1, 2, 3, …, n*.[23] FMC_t is the fixed overhead or maintenance cost of keeping a variety in the market for another period *t*. *I* represents the initial investment cost that firms incur in order to create a variety. The initial investment is a one-time sunk cost that determines firms' rate of yield growth potential. W_t and X_t are, respectively, price and market share of variety *i* at age *t*. These equations are obtained in the theoretical model in Chapter 2 and are represented in equations 3.6-b and 3.6-c, respectively. W_t and X_t are a function of the degree of specificity, μ, rate of yield potential growth, *k*, defined in 3.6-d, and number of firms, *n*. Degree of specificity is exogenous. Rate of yield potential growth, *k*, is a function of firms investment level, as defined in constraint 3.6-d. The parameter α in equation 3.6-d is exogenously determined. This parameter represents breeders' investment productivity.

Number of firms is determined through constraints 3.6-e and 3.6-f. Constraints 3.6-e and 3.6-f imply that a variety remains in the market as long as its revenue, $W_t X_t$, is larger than its fixed maintenance cost. Given the symmetry, each variety can only remain in the market for *n* periods. For any *t* larger than *n*, the revenue generated from a variety is larger than its fixed maintenance cost and the variety will no longer be in the market.

The above maximization problem is used to find the optimum investment levels for various levels of exogenous variables and several cost structures. Section 3.3.1 describes the assumptions used in order to perform the numerical simulations with endogenized rate of yield potential growth. Section 3.3.2 presents the equilibrium steady states conditions under the endogenized

[23] The sequences for both *i* and *t* end with *n* due to a symmetry between number of firms and length of product cycles; with *n* varieties in the market, each variety stays in the market for *n* periods. This symmetry is the result of the assumption that all varieties have the same degree of specificity and rate of yield potential growth.

rate of yield potential growth assumption. Section 3.3.3 presents some comparative statics of the exogenous variables.

3.3.1. Assumptions

Cost structure: It is assumed that seed producers incur two types of cost; an initial investment cost (*I*) and a fixed overhead or maintenance cost (FMC). The initial investment is a one-time sunk cost that determines firms' rate of yield growth potential. The fixed overhead or maintenance cost is the cost of keeping a variety in the market for another period. It is also assumed that firms have similar cost structures. That is, fixed maintenance cost and initial investment are equal for all firms. The initial investment, however, creates a unique rate of yield potential growth that determines each variety's yield potential level.

Equilibrium: Initial investment determines the rate of yield potential growth. Rate of yield potential growth determines profit levels. Therefore, numerical simulations find the optimal investment level such that each firm's total profit throughout the periods that its variety is in the market is maximized. Results represent Nash equilibrium in prices. Investment levels, however, are not Nash because it is assumed that all firms have the same investment level and the same rate of yield potential growth. Nevertheless, each firm behaves in accordance with its best response function assuming all firms follow the same rate of yield potential growth.[24]

Exogenous factors: There are three exogenous factors that affect this "investment-rate of yield growth potential- profit" relationship: 1) The relationship between investment and rate of yield potential growth, which refers to the seed producers' or breeders' investment productivity; 2) Degree of specificity of products, which could also be interpreted as the degree of heterogeneity of buyers; 3) Fixed maintenance cost. The relationship between investment and rate of yield potential growth determines how much rate of yield potential growth the industry can obtain for

[24] Although it is possible to allow each firm to decide on their yield potential levels without the assumption of fixed rate of yield potential growth, this does not contribute to this chapter significantly. This chapter is interested in effect of an increase or decrease in rate of yield potential growth and some exogenous factors on equilibrium prices, market shares, and number of firms. This is to understand how an industry characterized by sequential innovation evolves over time. Weather all firms follow the same rate of yield potential growth or are allowed to have different rates does not seem to be important for the purpose of this chapter. More importantly, if firms are allowed to have different rates of yield potential growth, then one needs to consider the possibility of an "innovation race" in which firms may not only invest more but also constantly change their cost structure in order to improve their investment productivity. These issues are not in the scope of this dissertation.

every investment dollar. A higher rate of yield potential growth per investment dollar implies a higher level of investment productivity.

3.3.2. Equilibrium Steady States

Numerical simulations are performed to find the optimal investment level, rate of yield potential growth, market shares, prices, and profit levels at equilibrium steady states (ESS). It is assumed that degree of specificity μ, fixed maintenance cost (FMC), and the relationship between investment I and rate of yield potential growth k are exogenous, where $k = I^{\alpha}$. The Solver function in Microsoft Excel is used to find the investment level that maximizes the total profit for each variety over the ESS. That is, profit maximization is not performed for the transition period before the ESS but only for the ESS. Given the symmetry between varieties at ESS, optimal investment level for all varieties is exactly the same.

Tables 3.6 to 3.8 below present the market shares, prices, and profit levels at the ESS for μ =14, FMC=0.01, and k=$I^{0.5}$. This level of exogenous variables results in an optimum investment level of I*=0.73 and a yield growth potential of k=0.86. For this set of exogenous variables and optimal investment level, the market reaches the ESS with 7 varieties. That is, with the introduction of variety 8 variety 1 leaves the market, with the introduction of variety 9 variety 2 will leave the market, and so on. This is because with the introduction of newer varieties with new characteristics and higher yield potential levels the older varieties will have to be priced so low and obtain so little market share that their profit levels can no longer cover the fixed overhead or maintenance cost (FMC) of keeping them in the market.

Table 3. 5. Distribution of Market Shares for *k=I* $^{0.5}$, μ = 14, and *FMC=0.01* (*I*=0.73*).

Time / Variety	1	…	7	8	9
1			0.06	-	-
2			0.09	0.06	-
3			0.11	0.09	0.06
4			0.14	0.11	0.09
5			0.17	0.14	0.11
6			0.20	0.17	0.14
7			0.23	0.20	0.17
8				0.23	0.20
9					0.23
HHI					0.16

Source: Author's estimations.

Table 3. 6. Distribution of Prices for *k= I* $^{0.5}$, μ = 14, and *FMC=0.01* (*I*=0.73*).

Time / Variety	1	…	7	8	9
1			0.95	-	-
2			1.41	0.95	-
3			1.87	1.41	0.95
4			2.33	1.87	1.41
5			2.79	2.33	1.87
6			3.26	2.79	2.33
7			3.72	3.26	2.79
8				3.72	3.26
9					3.72

Source: Author's estimations.

Table 3. 7. Distribution of Profit Levels for *k= I* $^{0.5}$, μ = 14, and *FMC=0.01* (*I*=0.73*).

Time / Variety	1	…	7	8	9
1			0.05	-	-
2			0.11	0.05	-
3			0.20	0.11	0.05
4			0.32	0.20	0.11
5			0.47	0.32	0.20
6			0.64	0.47	0.32
7			0.84	0.64	0.47
8				0.84	0.64
9					0.84
Net Revenue (NR)					2.62
Total Profit (NR-I*)					1.89

Source: Author's estimations.

As shown in Table 3.8, profits are non-zero. This may seem counter-intuitive, as one would expect a zero-profit condition to hold in the ESS. The zero-profit condition is well-stablished in the economics literature. DeBrock (1985), for example, claims that, in an R&D market, "the number of firms entering the race for the patent will increase until the present value of expected profit is driven to zero." The current study, however, provides an interesting point regarding the zero-profit condition in monopolistic competition markets. The profit levels that are reported in Table 3.8 and other tables in the remaining of this chapter are the profit levels that firms can obtain without encouraging entry of a new product. Firms do this through underinvestment. That is, firms could investment more to derive profit levels to zero with the same number of firms but they slightly underinvest to make small amount of profit that is not large enough to encourage entry. That is, the profit levels reported in Table 3.8 are slightly above normal but they are not enough to pay for initial investment and fixed maintenance cost of a new product.

3.3.3. Comparative Statics

Degree of specificity: One of the important exogenous determinants of optimal investment, number of equilibrium varieties, and other equilibrium conditions is the degree of specificity of varieties. As degree of specificity decreases varieties become more similar and number of equilibrium varieties decreases. This section seeks to explore how a higher or a lower degree of specificity and the resulted change in the ESS number of varieties affects the optimal level of investment.

Tables 3.9 to 3.11 below repeat the simulations presented in tables 3.6 to 3.8 with a lower degree of specificity of $\mu = 7$ rather than $\mu = 14$. Results indicate a decrease in the ESS number of varieties (from 7 to 5) and an increase in HHI for market concentration (from 0.16 to 0.23). Also, as shown in figures 3.5 and 3.6, with $\mu = 7$ prices and profit levels are significantly lower than the case of $\mu = 14$. This is due to the fact that competition increases as the degree of specificity decreases. The increased competition and lower profit levels result in a lower optimal investment level of $I^*=0.66$ compared to $I^*=0.73$ with $\mu = 14$. A lower optimal investment level, of course, results in a lower rate of yield potential growth of $k=0.81$ compared to $k=0.86$.

Table 3. 8. Distribution of Market Shares for $k = I^{0.5}$, μ = 7, and *FMC=0.01* (*I*=0.66*).

Variety \ Time	1	…	5	6	7
1			0.10	-	-
2			0.15	0.10	-
3			0.20	0.15	0.10
4			0.25	0.20	0.15
5			0.30	0.25	0.20
6				0.30	0.25
7					0.30
HHI					0.23

Source: Author's estimations.

Table 3. 9. Distribution of Prices for $k = I^{0.5}$, μ = 7, and *FMC=0.01* (*I*=0.66*).

Variety \ Time	1	…	5	6	7
1			0.85	-	-
2			1.30	0.85	-
3			1.75	1.30	0.85
4			2.20	1.75	1.30
5			2.65	2.20	1.75
6				2.65	2.20
7					2.65

Source: Author's estimations.

Table 3. 10. Distribution of Profit Levels for $k = I^{0.5}$, μ = 7, and *FMC=0.01* (*I*=0.66*).

Variety \ Time	1	…	5	6	7
1			0.07	-	-
2			0.18	0.07	-
3			0.34	0.18	0.07
4			0.54	0.34	0.18
5			0.80	0.54	0.34
6				0.80	0.54
7					0.80
Net Revenue (NR)					1.93
Total Profit (NR-I*)					1.27

Source: Author's estimations.

Figures 3.4 to 3.6 compare the ESS market shares, prices, and profit levels presented in tables 3.8 to 3.10 to the ones presented in tables 3.9 to 3.11, 3.13 to 3.15, and 3.16 to 3.18. In figures 3.4 to 3.6 the blue curve is the baseline with $k = I^{0.5}$, μ=14, and FMC=0.01, the red curve represents a lower degree of specificity μ=7, the green curve represents higher investment productivity ($k= I^{0.9}$), and the purple curve presents a higher fixed maintenance cost (FMC=0.05) compared to the baseline.

Comparison of the blue and the red curves in figures 3.4 to 3.6 indicates that a lower degree of specificity results in a shorter but steeper disadoption curve, lower prices, and lower profit levels. Shorter but steeper disadoption curves also imply fewer products. These findings provide reassuring insight into why firms seek to differentiate their products (i.e. increase the degree of specificity of their products).

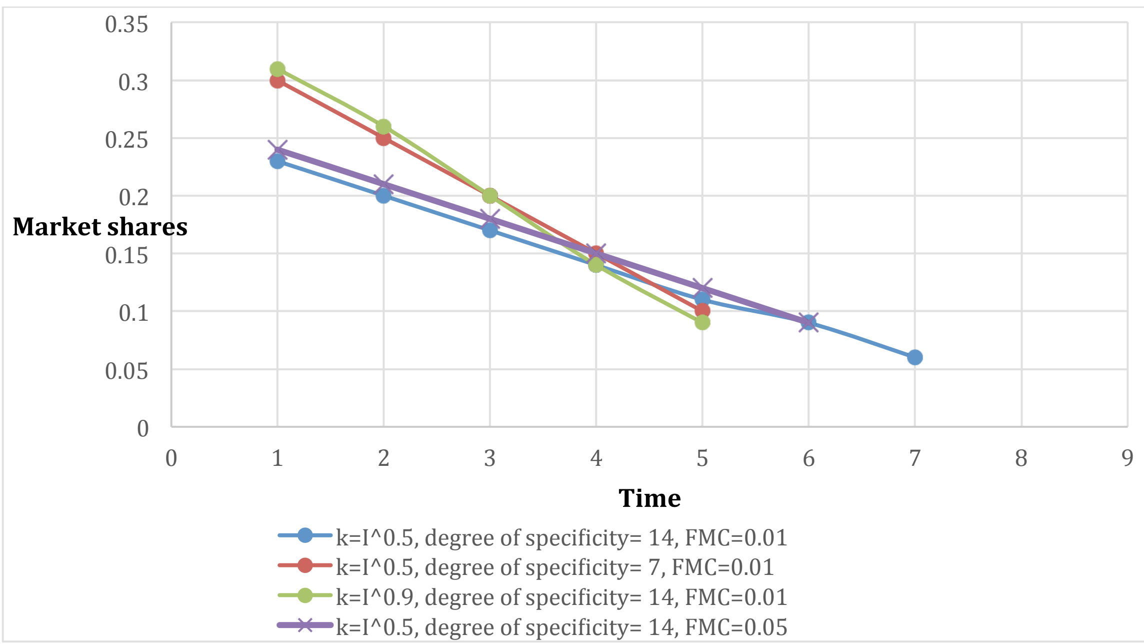


Figure 3. 4. Effect of Degree of Specificity and Investment Productivity on Length of Product Cycles.

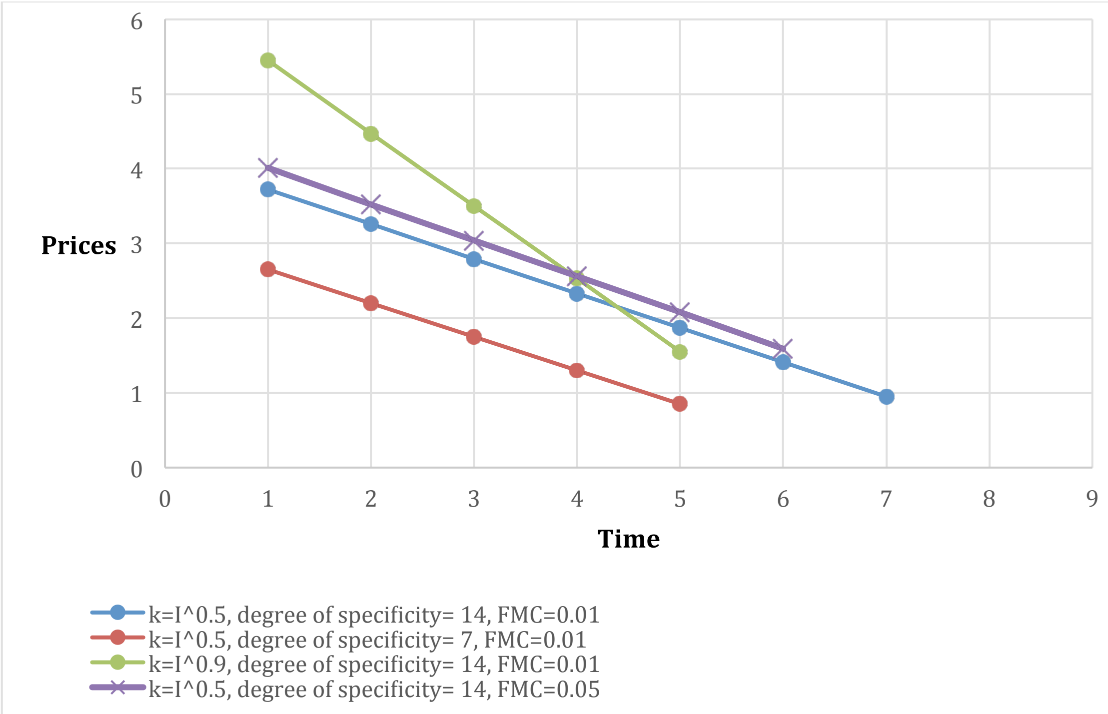


Figure 3. 5. Effect of Degree of Specificity and Investment Productivity on Prices.

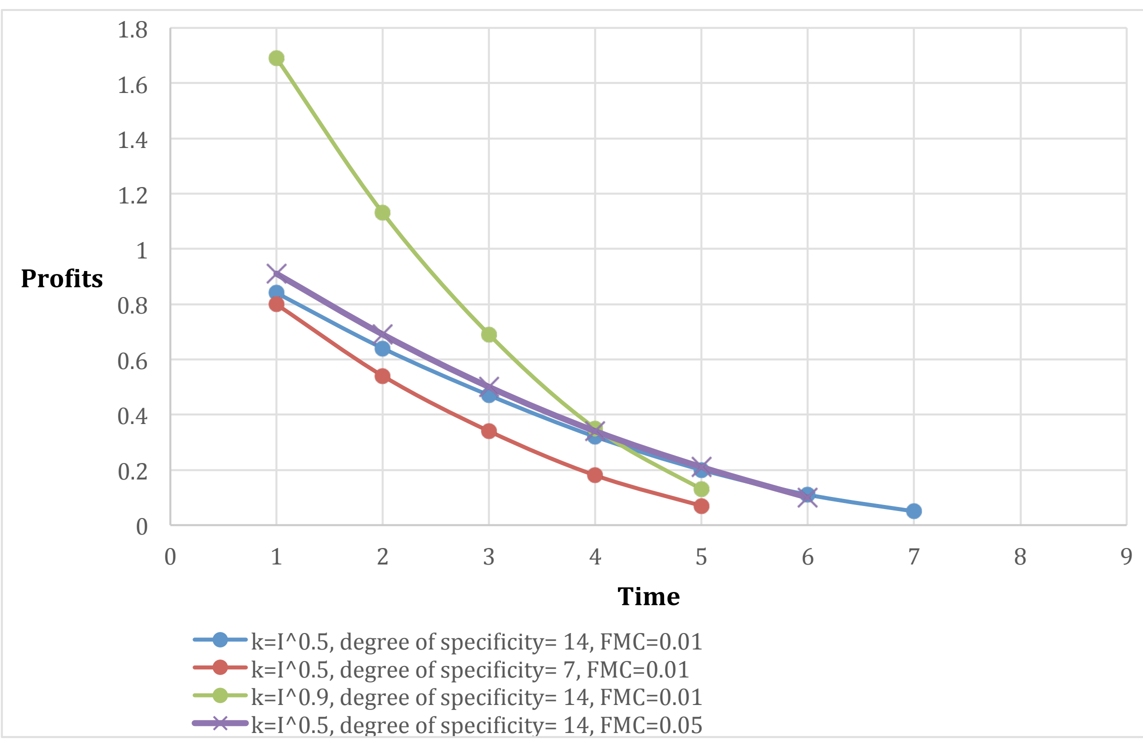


Figure 3. 6. Effect of Degree of Specificity and Investment Productivity on Profit Levels.

However, effect of degree of specificity on number of varieties and optimal investment, is not as straightforward as depicted above. In general, an increase in degree of specificity implies more varieties in the market and an increase in optimal investment level. The change in number of firms as a result of an increase in degree of specificity, however, is not continuous. That is, the increase in degree of specificity must be large enough to allow for entry of a new variety. Otherwise, the existing varieties adapt to the new levels of degree of specificity. Table 3.12 provides an example. As degree of specificity increases from 0.5 to 2, number of varieties at ESS remains 3. This is because the increase in degree of specificity is not large enough to allow for entry of the third variety. For a given number of varieties, say 3 in the following table, as degree of specificity increases varieties become more differentiated and have greater incentives to invest more in the improvement of their varieties. Therefore, optimal investment increases as degree of specificity increases, as long as entry does not occur. In the following table, for example, as degree of specificity increase from 0.5 to 2, number of varieties remains at 3, optimal investment level increases from 0.01 to 0.34 while total future profit for each variety increases from 0.22 to 0.71. However, as soon as entry occurs, firms lose their incentive to invest and optimal investment level drops.

Table 3. 11. Effect of Degree of Specificity on Number of Firms, Optimal Investment, and Profit.

Mu	Optimal Investment	K	Total Profit per Firm	Number of firms at ESS
0.3	-	-	-	1
0.4	0.04	0.204	0.35	2
0.5	0.01	0.10	0.22	3
0.6	0.016	0.13	0.27	3
0.7	0.02	0.16	0.31	3
0.8	0.04	0.19	0.35	3
0.9	0.05	0.22	0.40	3
1	0.06	0.25	0.43	3
2	0.34	0.59	0.71	3
3	0.25	0.50	0.81	4
4	0.49	0.70	0.95	4
6	0.46	0.68	1.17	5
8	0.89	0.95	1.33	5
10	0.67	0.82	1.56	6

Source: Author’s estimations.

This finding provides additional insights into why firms prefer to differentiate their products. With more differentiated products, higher profit levels can be accommodated. However, after a certain threshold, entry occurs and firms must share the market and profits with the new entrant. To compensate for this effect, firms can increase the level of differentiation (i.e. degree of specificity) of their products.

Breeder investment productivity: This section is concerned with the effect of breeders' investment productivity on optimal investment level. The relationship between investment and rate of yield potential growth determines how much yield potential growth the industry can obtain for every investment dollar. This relationship also represents the seed producers' economies of size as a higher rate of yield potential growth per investment dollar implies a lower average cost level for any given level of yield potential growth.

In order to show the effect of investment productivity on optimal investment, two different levels of investment productivity are compared. $k= I^{0.9}$ represents a higher level of investment productivity than $k= I^{0.5}$. Tables 3.13 to 3.15 below repeat the simulations presented in tables 3.6 to 3.8 with $k= I^{0.9}$ rather that $k= I^{0.5}$. Comparison of tables 3.13 to 3.15 and tables 3.6 to 3.8 indicates that with higher breeder productivity number of firms decreases from 7 to 5, competition decreases, and firms have an incentive to invest more. Therefore, the optimal investment level increases. In the following example, $k= I^{0.9}$ implies an optimal investment level of $I^*=1.86$ and a rate of yield growth of $k=1.75$, whereas in case of $k= I^{0.5}$ optimal investment level is $I^*=0.86$ and rate of yield growth is $k=0.73$.

Table 3. 12. Distribution of Market Shares for *k*= *I* $^{0.9}$, *μ* = 14, and *FMC=0.01* (*I=1.86).**

Time / Variety	1	…	5	6	7
1			0.09	-	-
2			0.14	0.09	-
3			0.20	0.14	0.09
4			0.26	0.20	0.14
5			0.31	0.26	0.20
6				0.31	0.26
7					0.31
HHI					0.23

Source: Author's estimations.

Table 3. 13. Distribution of Prices for *k*= *I* $^{0.9}$, *μ* = 14, and *FMC=0.01* (*I=1.86).**

Time / Variety	1	…	5	6	7
1			1.55	-	-
2			2.53	1.55	-
3			3.50	2.53	1.55
4			4.47	3.50	2.53
5			5.45	4.47	3.50
6				5.45	4.47
7					5.45

Source: Author's estimations.

Table 3. 14. Distribution of Profit Levels for *k*= *I* $^{0.9}$, *μ* = 14, and *FMC=0.01* (*I=1.86)**

Time / Variety	1	…	5	6	7
1			0.13	-	-
2			0.35	0.13	-
3			0.69	0.35	0.13
4			1.13	0.69	0.35
5			1.69	1.13	0.69
6				1.69	1.13
7					1.69
Net Revenue (NR)					3.99
Total Profit (NR-I*)					2.13

Source: Author's estimations.

Also, comparison of the blue and the green curves in figures 3.4 to 3.6 reveals that higher breeder productivity results in a shorter but steeper disadoption curve, higher average price and profit levels with a steeper path. A shorter but steeper disadoption curve also implies fewer products and, consequently, an increase in the HHI of market concentration from 0.16 to 0.23. These findings also show how greater economies of size may accommodate higher profit levels for firms.

Similar to the effect of degree of specificity, the change in number of varieties as a result of a change in investment productivity is not continuous. The change in investment productivity must be large enough to allow for entry or exit of a variety. Otherwise, same number of varieties adapt to the change by changing their prices and investment levels that results in a change in their market shares and profit levels.

Fixed Maintenance Cost: fixed overhead or maintenance cost is the cost of keeping a variety in the market for another period. As long as a variety is in production the producer has to allocate some of their resources to that variety. This includes but is not limited to marketing and advertisement costs, reproduction costs, and storage costs. This section explores the effect of a change in the fixed maintenance cost on ESS number of varieties and optimal level of investment.

Tables 3.16 to 3.18 below repeat the simulations presented in tables 3.6 to 3.8 with a higher FMC of 0.05 rather than 0.01. Results show a decrease in ESS number of varieties (from 7 to 6) and an increase in HHI for market concentration (from 0.16 to 0.18). With a higher fixed maintenance cost, firms must discontinue their varieties sooner than they would with a lower fixed maintenance cost. As shown in figures 3.5 and 3.6, a higher FMC results in a shorter product cycle. Also, existence of fewer varieties in the market results in higher prices and profit levels.

Table 3. 15. Distribution of Market Shares for $k=I^{0.5}$, μ = 14, and *FMC=0.05* (*I*=0.78*).

Time / Variety	1	…	6	7	8
1			0.09	-	-
2			0.12	0.09	-
3			0.15	0.12	0.09
4			0.18	0.15	0.12
5			0.21	0.18	0.15
6			0.24	0.21	0.18
7				0.24	0.21
8					0.24
HHI					0.18

Source: Author's estimations.

Table 3. 16. Distribution of Prices for $k= I^{0.5}$, μ = 14, and *FMC=0.01* (*I*=0.78*).

Time / Variety	1	…	6	7	8
1			1.59	-	-
2			2.08	1.59	-
3			2.56	2.08	1.59
4			3.04	2.56	2.08
5			3.52	3.04	2.56
6			4.01	3.52	3.04
7				4.01	3.52
8					4.01

Source: Author's estimations.

Table 3. 17. Distribution of Profit Levels for $k= I^{0.5}$, μ = 14, and *FMC=0.01* (*I*=0.78*).

Time / Variety	1	…	6	7	8
1			0.10	-	-
2			0.21	0.10	-
3			0.34	0.21	0.10
4			0.50	0.34	0.21
5			0.69	0.50	0.34
6			0.91	0.69	0.50
7				0.91	0.69
8					0.91
Net Revenue (NR)					2.74
Total Profit (NR-I*)					1.96

Source: Author's estimations.

With higher fixed maintenance cost firms also have a higher optimal investment level of $I^*=0.78$ compared to $I^*=0.73$ and higher rate of yield potential growth of $k=0.88$ compared to $k=0.86$. This is because a higher fixed maintenance cost reduces the number of varieties in the market and, thereby, competition. The reduced competition enables the firms to invest more, charge higher prices, obtain larger market shares, and attain higher profit levels.

Similar to the effect of degree of specificity and breeders' investment productivity the change in number of varieties as a result of a change in the fixed maintenance cost level is not continuous. If the change is not large enough to allow for entry or exit of a variety, same number of varieties adapt to the change by changing their prices and investment levels that results in a change in their market shares and profit levels.

3.3. Conclusion

This chapter provides valuable insights into important policy issues such as why some industries consist of fewer firms than others, why investment levels are higher in some industries than others, why some products have longer life cycles while others leave the market faster. While these issues may have been explored from different perspectives in the literature, this study looks at these issues from the perspective of sequential innovation. [25]

Chapter 2 introduces a theoretical model that incorporates sequential entry of new production inputs that embody new characteristics while allowing older products to leave the market. Some properties of the model are shown in propositions and their algebraic proofs. Numerical simulations performed in this chapter provide further evidence to the validity of these propositions. Also, some of the key factors in the length and other characteristics of product cycles are investigated.

While Chapter 2 hypothesizes that rate of yield potential growth is an important determinant of market consolidation, this chapter provides more insight into this relationship. This chapter endogenizes the rate of yield potential growth as a function of firms' initial investment. Profit-

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[25] For example, Dasgupta and Stiglitz (1980) explore the effect of uncertainty on number of firms involved in R&D. DeBrock (1985) explores the issue of optimal patent life from the perspective of competition in R&D market. Grossman and Helpman (1991) explore the role of quality ladder in the theory of growth.

maximizing investment levels are found for firms. Finally, comparative statics are used to explore the effect of three exogenous variables on number of firms at the equilibrium steady states, optimal investment, and other equilibrium conditions. The exogenous variables include degree of specificity of seed varieties, breeders' investment productivity, and the fixed overhead or maintenance cost of keeping a variety in the market.

The current study provides some insights into the nature of product or business cycles. It is shown that products and market characteristics such as yield growth rate and degree of specificity of products determine the length and other characteristics of product cycles. For example, with a higher yield growth rate, product cycles become shorter but market shares at any given period are higher. In other words, the higher the quality of the imitators' products is, the shorter the products stay in the market and the larger their market shares are. This also implies a more concentrated market structure. This insight is comparable to the result of Dasgupta and Stiglitz (1980) study. They argue that a monopolist may use "fast research" as a means of preventing potential entry to the R&D market (Dasgupta and Stiglitz, 1980). However, factors determining the introduction of an original drastic innovation (e.g. the hybrid technology) and the length of the main wave (e.g. how long the hybrid technology in the seed industry remains in the market) are still unexplored.

Degree of specificity, breeders' investment productivity, and the fixed overhead cost of keeping a variety in the market are important determinant of optimal investment level, number of varieties, prices, market shares at the equilibrium steady states and consolidation. More specific varieties imply more varieties in the market, higher prices, and an increase in optimal investment level. Greater investment productivity implies fewer varieties in the market, higher prices, higher profit levels, higher optimal investment, and higher consolidation. A higher FMC results in a shorter product cycle, fewer varieties in the market, higher prices and profits, higher optimal investment, and higher consolidation.

In short, degree of specificity of products, which also represents the degree of heterogeneity of consumers, as well as firms' cost structure, particularly investment productivity, which represents economies of size, seem to have a key role in determining an industry's number of firms, length of product cycles, prices, profits, investment levels, rate of growth, and consolidation level.

Last but not least, results of this study provide very interesting insights into the impact of differentiation on equilibrium conditions. While the common belief is that differentiation can increase a firm's profit, the numerical simulations show that this relationship is not as straightforward. It is shown that increased differentiation, if followed by the rivals, will certainly result in increased profit as long as it is not followed by entry of new firms. However, if increased differentiation creates enough space in the market for a new entrant, then entry of a new rival will increase competition and may result in a decrease in the incumbents' profit.

Chapter 4: Empirical Estimations

4.1. Introduction

Chapter 2 introduced a new theoretical model that explains the incentives to create new characteristics for new production inputs. This model incorporates sequential entry of new production inputs that embody new characteristics, while allowing older production inputs to leave the market when their market share falls to the point where they are no longer viable. In Chapter 2 properties of the model were also shown in form of propositions and algebraic proofs. In chapter 3, numerical simulations were performed to further investigate the validity of these propositions, and provide more insight into dynamic aspects of the model, such as product cycles.

The current chapter uses data from Canadian canola industry to empirically test some of the propositions discussed in chapter 2. Specifically, this chapter tests propositions 2 and 4. Proposition 2 states that market share of a variety increases as its degree of specificity decreases, *ceteris paribus*. Proposition 4 indicates that a higher rate of yield potential improvement results in a higher market share for the variety with highest yield potential level, *ceteris paribus*.

This chapter tests the effect of yield potential and degree of specificity on market shares of Canadian canola seed varieties. While price data for individual canola varieties in Canada are unavailable, time series of market shares for each variety in various locations are available. Therefore, this chapter merely focuses on empirical test of the propositions that hypothesize the effect of different parameters on market share.

While the literature on adoption of seed varieties has explored many determinants of crop adoption, less attention has been paid to propositions 2 and 4 that discuss the effect of yield potential and degree of specificity on adoption of seed varieties. Most previous studies have used average actual yield and some have also used yield variance in order to measure the effect of yield on adoption. This study uses yield potential and degree of specificity to explore the effect of yield on adoption. Yield potential and degree of specificity refer to a variety's yield at the top yielding location and the degree by which the variety's yield decreases as its area expands, respectively. It is shown later in this chapter that yield potential and degree of specificity, together, are likely to provide a more accurate measure of a variety's performance over numerous locations than average and variance yield.

The purpose of this chapter is to provide empirical evidence on the effect of yield potential and degree of specificity on adoption of seed varieties. In addition, this chapter provides empirical evidence as to why it is important to incorporate both seed and location characteristics when constructing a demand model for the seed industry.

In order to empirically test the validity of propositions 2 and 4, the effect of yield potential and degree of specificity is estimated on market shares of Canadian canola seed varieties using regression analyses. This is done in two steps. First, yield potential and degree of specificity of canola seed varieties is estimated in a way consistent with the theoretical model. Second, the effect of yield potential and degree of specificity on market shares of these varieties is estimated using a panel regression model.

The next section describes the dataset. In section 4.3 yield potential and degree of specificity of canola seed varieties is estimated. Section 4.4 discusses the choice of functional form and explanatory variables and then presents estimation results. Further discussion of the results is presented in section 4.5. Section 4.6 provides a conclusion of the empirical study.

4.2. Dataset

This study uses two datasets, one from Manitoba and one from Saskatchewan for comparison purposes. Appendices G and H present the data used in this chapter.

The Manitoba dataset goes from 2004 to 2013 and includes 42 varieties. Appendix B of this chapter presents number of years, test locations, varieties with consistent data, potential observations. As presented in Table 4.B2, Manitoba datasets consist of 420 potential observations. Manitoba data on both area and yield levels in various locations is obtained from Manitoba Crop Insurance Corporation.

The Saskatchewan dataset only includes 2007, 2008, 2009, 2010, 2011, and 2012. As presented in Table 4.B1, the number of varieties that have been tested in trails each year is different. The

Saskatchewan dataset consists of only 17 varieties with consistent data for at least 2 years (see Table 4.B2). The majority of Saskatchewan data is obtained from two sources. Data on canola varieties' area is obtained from Saskatchewan Crop Insurance Corporation reports. Yield data for Saskatchewan varieties is obtained from Canola Performance Trial Reports and Prairie Canola Variety Trials Test Results. Appendices G and H present Manitoba and Saskatchewan datasets, respectively.

Exploring the information in canola trial reports reveals some interesting facts about factors that influence yield variations. Figures 4.1 and 4.2 illustrate the yield of canola seed varieties at different locations in 2011 and 2012. Looking at each of these two figures reveals that: 1. Each variety yields differently at different locations (variety effect), 2. At each location, different varieties yield differently (location effect). Comparing the two figures reveals the third interesting fact: 3. Top-yielding locations are not the same every year. For example, in 2011 Dawson Creek and Westlock are the top-yielding locations while in 2012 Fort Saskatchewan and Saskatoon are the top-yielding locations. This effect could be attributed to changes in weather conditions from year to year, which influences the yield levels at different locations differently (weather or year effect). To summarize, variations in yield levels depicted in the following figures can be attributed to variety effects, location effects, and weather (year) effects. It is worth noting that although not presented in this chapter, yield levels of canola varieties in other years (2007 to 2010) follow similar patterns as those depicted in Figures 4.1 and 4.2 emphasizing the importance of variety, location, and weather effects.

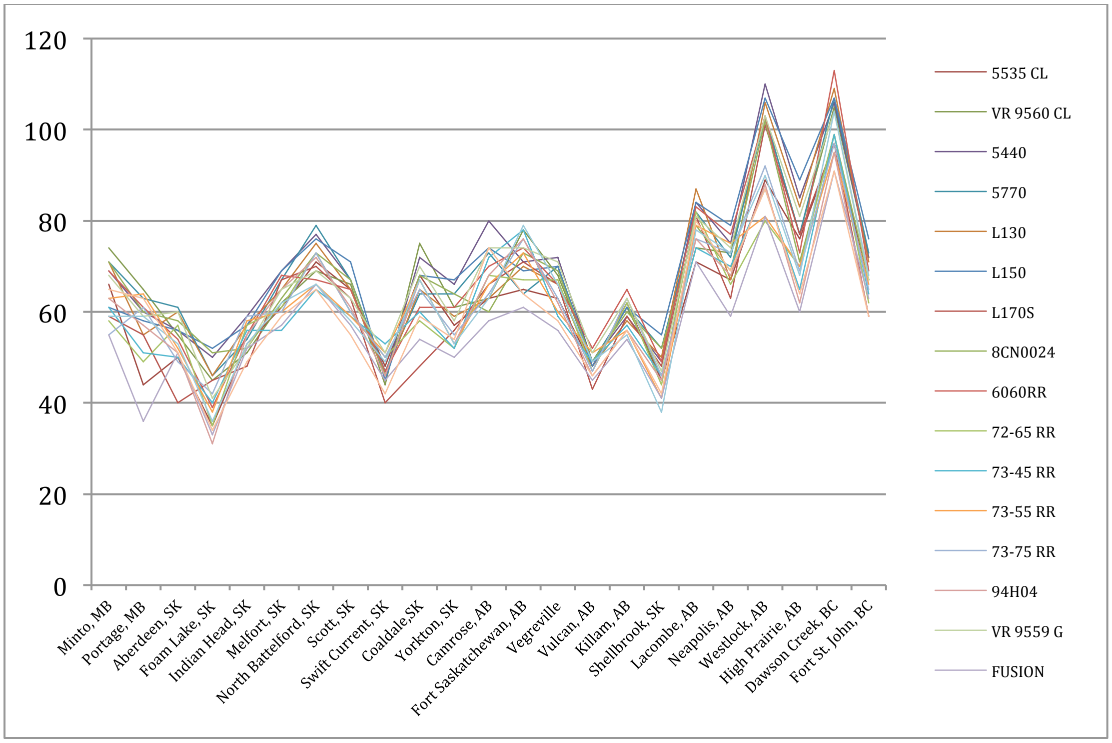

Figure 4. 1. Yield of Canola Seed Varieties in Different Locations in 2011 (bu/acre).

Source: Canola Council of Canada, *Canola Performance Trials* report, 2011.

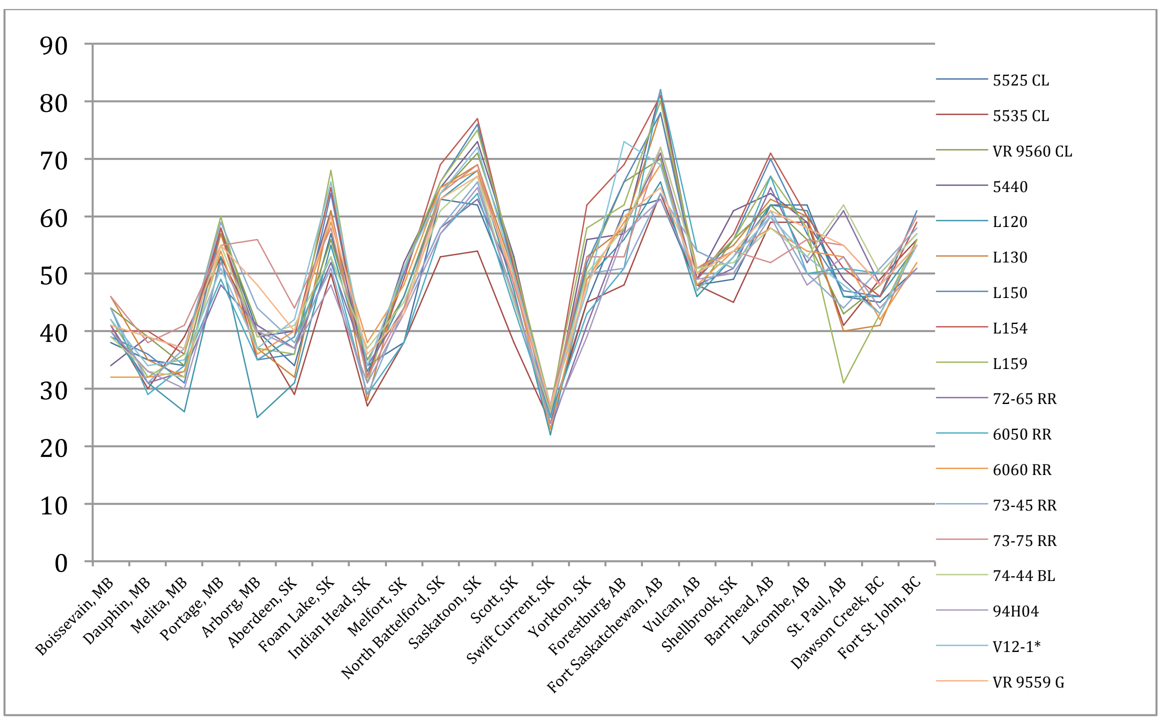

Figure 4. 2. Yield of Canola Seed Varieties in Different Locations in 2012 (bu/acre).

Source: Canola Council of Canada, *Canola Performance Trials* report, 2012.

Figures 4.1 and 4.2 emphasize the importance of incorporating both variety and location characteristics when constructing a demand model for the seed industry. However, statistical tests need to be performed in order to estimate the role that each of variety, location, and weather (year) effects and their interactions play in yield variations.

UNIANOVA tests are performed to find the sources of yield variations and their relative magnitude. Several specifications have been tried to find the model that provides the most consistent intuitions and also fits the data well.

The model presented in Table 4.1 indicates that variety, location, year, and their two-way interactions explain 97% of the variations in yield. Location has the largest "effect size" with *partial eta squared* of 0.88. Interestingly, weather has the lowest effect size of 0.27. However, interaction of location and weather has a relatively large effect size. This means weather mainly influences yield through location. Interaction of location and variety effects is also highly significant with a relatively large *partial eta squared*. This reemphasizes the importance of interaction between genetics and environment (Haldane, 1946). Therefore, it is important incorporate variety and location effects in the theoretical model in chapter 2.

Table 4. 1. Three-Way ANOVA (UNIANOVA) with 6 Fixed Factors.

Tests of Between-Subjects Effects

Dependent Variable: Yield

Source	Type III Sum of Squares	df	Mean Square	F	Significance	Effect Size (*Partial Eta Squared*)
Corrected Model	2339746[a]	3622	646	9.66	0.00	0.97
Intercept	6811117	1	6811117	101887	0.00	0.99
Location	505398	56	9025	135	0.00	0.88
Variety	314471	114	2758	41	0.00	0.82
Weather	25060	4	6265	94	0.00	0.27
Location*Weather	317658	77	4125	62	0.00	0.82
Location*Variety	330507	3316	100	1.49	0.00	0.83
Variety * Weather	46937	55	853	12.76	0.00	0.41
Error	67318	1007	67			
Total	15761459	4630				
Corrected Total	2407063	4629				

a. R Squared = .972 (Adjusted R Squared = .871)

Source: Author's estimation.

4.3. Estimation of yield potential and degree of specificity

Assuming that land is uniformly distributed between the best-suited and worst-suited parcels, and that land parcels are arbitrarily small, then the decline in yield of each variety will be a continuous linear function of the amount of land allocated to that variety. Chapter 2 defines the relationship between yield and area of variety *i* as follows:

$$Y_i = \hat{y}_i - \mu_i X_i$$

where Y_i is yield of variety *i* per acre, $\hat{y}_i$ potential yield of variety *i* per acre (i.e. yield at the best-suited parcel), X_i area or number of parcels allocated to variety *i*, and μ_i is the yield decrease of variety *i* as its area expands by one unit. The above equation indicates that each variety *i* yields most at a particular parcel of land (i.e. yield potential) and its yield drops in a linear fashion by the rate of μ_i as area X_i allocated to variety *i* expands.[26] In other words, μ_i reflects the degree of specificity of variety *i* for different parcels of land. A larger μ_i means yield of variety *i* drops faster as area expands and this implies variety *i* is well-suited to specific parcels of land and *vice versa*.

[26] With non-uniform distribution of parcels of land the relationship between yield and area of variety *i* (equation 4.1) becomes non nonlinear, and with parcels of land that are not arbitrarily small the continuous linear function turns into a step function.

Table 4. 2. Yield Levels of Canola Seed Varieties at 4 Trial Locations in 2012.

		Boissevain, MB	Dauphin, MB	Melita, MB	Portage, MB
ClearField	5525 CL	38	35	34	58
	5535 CL	41	30	39	53
	VR 9560 CL	44	39	34	58
Liberty Link	5440	34	39	37	57
	L120	40	31	26	53
	L130	46	35	32	57
	L150	39	36	31	58
	L154	40	40	36	58
	L159	42	32	36	60
Roundup Ready	72-65 RR	41	31	33	48
	6050 RR	44	29	34	49
	6060 RR	32	32	33	54
	73-45 RR	44	31	37	59
	73-75 RR	46	38	41	55
	74-44 BL	39	33	32	55
	94H04	40	33	30	52
	V12-1*	42	34	35	51
	VR 9559 G	41	39	37	55
	VT 520 G	35	36	33	52
	1990	29	34	36	54
	1970	36	31	25	54
	1999	48	39	38	55
	74-47 CR	-	-	-	-
	73-15 RR	-	-	-	-

Source: Canola Council of Canada, *Canola Performance Trials* report, 2012.

In order to empirically estimate the yield potential and degree of specificity of canola seed varieties the following steps have been followed:

1. Yield levels of all the available varieties at all the reported locations are identified. In Saskatchewan this is limited to tested varieties at test locations whereas in Manitoba the dataset includes all the varieties above the minimum tolerance of 500 acres or 3 farms in a rural municipality. Table 4.2 shows a part of the dataset for all the tested varieties at 4 trials in 2012.

2. Yield for each variety is ranked from the highest yielding location to the lowest yielding location. Thus, for each variety there are several data points ranked in descending order. Table 4.3 and Figure 4.3 show the yield levels for four canola varieties at 23 test locations in 2012 ranked in descending order.
3. For each variety a regression line that fits the data points best is estimated using OLS. Intercept and slope of this line are yield potential and degree of specificity for each variety. These measures are presented for the four varieties in Table 4.3 and Figure 4.3.

Table 4. 3. Yield Levels of Four Canola Varieties at 23 Test Locations in 2012.

	Varieties			
Location	5525 CL	5535	VR 9560	5440
1	63	64	71	82
2	63	59	70	73
3	62	59	66	65
4	62	56	64	64
5	62	54	62	61
6	61	53	58	61
7	58	53	56	59
8	57	50	56	57
9	51	49	56	57
10	49	48	55	56
11	48	48	52	55
12	46	45	51	53
13	46	45	48	52
14	45	41	47	49
15	45	41	46	49
16	40	40	44	43
17	38	39	43	40
18	38	38	41	39
19	35	38	39	39
20	34	30	37	37
21	34	29	35	34
22	34	27	34	32
23	25	24	27	25
Slope (degree of specificity)	**-1.7**	**-1.6**	**-1.7**	**-2**
Intercept (Yield	**67.9**	**63.6**	**71.3**	**75.2**

Source: Canola Council of Canada, *Canola Performance Trials* report, 2012, and author's calculations.

It is important to point out that μ_i measures how fast yield of variety i drops from its highest to its lowest yielding location. As emphasized in Chapter 2, degree of specificity, μ, is determined by the interaction of seed and land characteristics over a spectrum of locations, not the distance between those locations. By definition, degree of specificity shows whether a variety can be planted in many different locations or is very specific to a certain cluster of locations, regardless of the distance between the locations. Therefore, the effect of actual physical distance between the locations must not influence the degree of specificity. This is why, as shown in Figure 4.3, in estimation of μ the locations are assumed equally distanced for all varieties in all years.

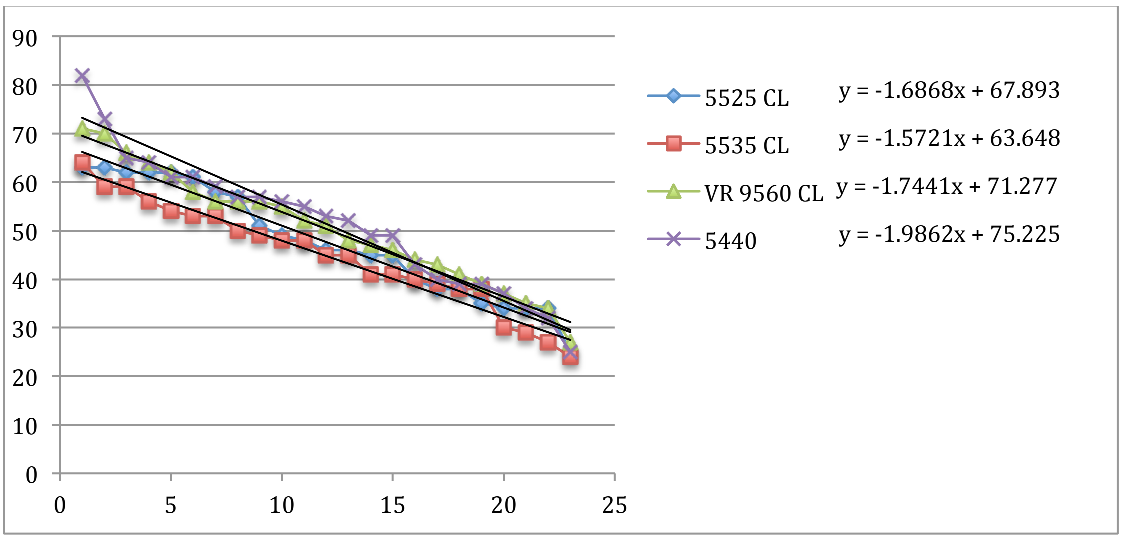

Figure 4. 3. Yield Levels of Four Canola Varieties at 23 Test Locations in 2012.

Source: Canola Council of Canada, *Canola Performance Trials* report, 2012, and author's estimations.

4.4. Estimation of effects of yield potential and degree of specificity on market shares

4.4.1. Introduction

In this section an empirical test of propositions 2 and 4 is performed. For this purpose, effect of yield potential and degree of specificity of various varieties on their market shares is estimated using an econometrics model. Literature on crop adoption is used to determine the variables that have a potential impact on market shares of seed varieties. One of the contributions of this study is to add yield potential and degree of specificity of varieties as determinants of crop adoption. Results show that these two are important determinants of market shares of seed varieties.

4.4.2. Regression model

Simple pooled regressions have been used in most of the studies that estimate the adoption curves of seed varieties (Barkley and Porter, 1996; Covey, 2012; Dahl et al., 1999; Gambrell, 2004). The implicit assumption in a pooled model is that variations in market shares of all the varieties follow a similar pattern. However, as shown in the UNIANOVA results in Table 4.1, different varieties behave differently at different locations and under different weather conditions. In other words, empirical evidence shows that there is something intrinsic to each variety that differentiates it from other varieties. One of the basic assumptions of the theoretical model presented in chapter 2 is that each variety in the market is differentiated from all the other varieties. Therefore, it is possible that different varieties have different adoption patterns. Barkley and Porter (1996), Covey (2012), Dahl et al. (1999), and Gambrell (2004) partially capture this differentiation by incorporating independent variables for seed characteristics in their models. However, it seems very difficult, if not impossible, to incorporate all of the differentiating characteristics, especially because some seed traits may be unobservable and/or non-quantifiable for econometricians. In such a case, the least squares estimator in the pooled regression omits the heterogeneity of varieties (i.e. cross-sections). Greene (2012, p350) suggests "omitting (or ignoring) the heterogeneity when the fixed effects model is appropriate renders the least squares estimator inconsistent—sometimes wildly so." Assuming it were possible to observe, quantify, and incorporate all the differentiating characteristics of all the varieties, the model would still be likely to suffer from very low degree of freedom when time series are short.

Therefore, instead of a pooled regression, this study uses a panel regression with varieties as fixed effects to take into account the fact that each variety is differentiated from all the other varieties. A poolability F-test is performed to show that the fixed effect panel regression is preferred to a pooled regression. The procedure and results of the poolability test are presented in Appendix C. With this innovation, the fact that all the varieties are differentiated from one another without running into low degree of freedom problem is incorporated. Results of both panel and pooled regressions are presented in Table 4.4 for comparison. Using a panel model with variety fixed effects is another contribution of this study to the literature on adoption of seed varieties.

The fixed effects model is also preferable to a random effects model because: 1. This study is concerned with a specific set of *N* varieties (Baltagi, 2005;p11); 2. The variety (fixed) effects are not assumed to be independent of the set of explanatory variables (Baltagi, 2005;p19). For example, variety (fixed) effects, which basically represent characteristics intrinsic to each variety, are very likely to have an effect on explanatory variables such as yield potential and degree of specificity.

The following equation represents the fixed effects panel regression model that is estimated in this study:

(4.1) $$Y_{it} = \alpha + X_{it}\beta + u_{it} \qquad i = 1, \dots, N; t = 1, \dots, T$$

with i denoting seed varieties, t denoting time, Y_{it} representing market share of variety i in year t, and X_{it} representing the set of explanatory variables. α is a scalar and β is the set of parameters to be estimated (Baltagi, 2005;p11). Baltagi (2005; p11-12) defines the one-way error component u_{it} for the fixed effects model as follows:

(4.2) $$u_{it} = Z_i\mu_i + v_{it}$$

where Z_i is the set of individual (variety) dummies, μ_i is the set of fixed parameters to be estimated. These parameters denote the *unobservable* variety-specific effects. v_{it} captures the remainder stochastic disturbances. v_{it} is assumed to be independent and identically distributed $IID(0, \sigma_v^2)$ (Baltagi, 2005;p11-12). In this study, individual (variety) dummies capture observable and unobservable seed characteristic such as brand, technology, and traits. As mentioned earlier, previous studies such as those of Barkley and Porter (1996), Covey (2012), Dahl et al. (1999), and Gambrell (2004) partially capture the observable characteristics that are intrinsic to each variety by incorporating independent variables for seed characteristics in a pooled regression model.

Dependent variable Y_{it} used in equation 4.2 is the share of variety i in the total area of canola in Saskatchewan/Manitoba in year *t*. This variable is in percentage and represented with *Market Share* in the estimation results.

The set of explanatory variables X_{it} in equation 4.1 includes:

1. Lagged degree of specificity (*Lag Mu*);
2. Lagged yield potential (*Lag YP*);
3. Number of months a variety has been in the market as polynomial of the third degree (T, T^2, and T^3).

The logic behind selecting the above explanatory variables is provided below.

Degree of specificity: As stated in proposition 4, as a variety becomes more specific its market share decreases, *ceteris paribus*. The impact of degree of specificity on market share has not been explored in the literature. Similar measures such as yield variance have been used in adoption models (Barkley and Porter, 1996). The theoretical framework in this study, however, shows that it is the combination of yield potential and degree of specificity that determine seed varieties' market shares. This study argues that yield potential and degree of specificity, together, are likely to provide a more accurate measure of a variety's performance over numerous locations than average and variance yield. The argument is based on the fact that average and variance (first and second moments) of yield do not provide a comprehensive measure of adaptability. Previous studies presume that a variety with higher yield variance level is less adaptable than one with the same average yield but lower variance. Here, a counterexample is provided to show how two varieties with very different degrees of adaptability may have the same average and variance yield. Assume canola variety A can be seeded in 10 locations while canola variety B can be seeded in 20 locations. This is simply because variety B is more adaptable. Also assume that each location is one acre. Figure 4.4 below shows varieties A and B with the same average and variance yield but different adaptability levels.

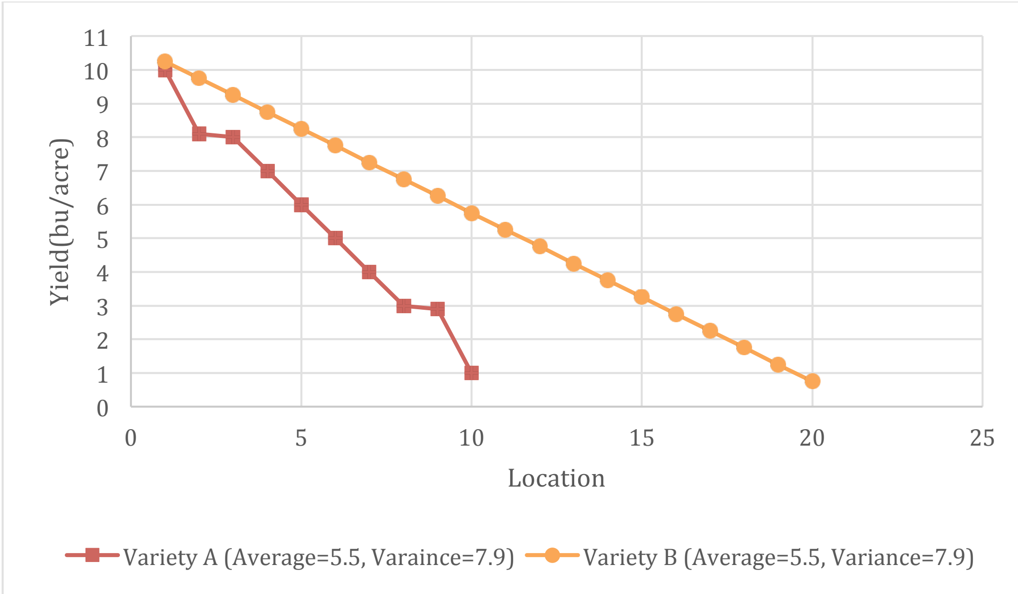

Figure 4. 4. Yield Levels of Four Canola Varieties at 23 Test Locations in 2012.

Source: *Source*: Author's calculations.

As shown in Figure 4.4 above, based on measures of first and second moment one could come to the conclusion that varieties *A* and *B* are very much the same, regardless of the fact that variety *A* is less adaptable and can be used in only 10 locations and offers a total production of 55 bushels in 10 locations while variety *B* is more adaptable, can be in 20 locations, and offers a total production of 110 bushels in 20 locations. That is, variance may fail to distinguish varieties with respect to their adaptability levels. However, measures of yield potential (i.e. intercept or yield at the top yielding location) and degree of specificity (i.e. slope or the degree by which a variety's yield drops as area expands), not only provide a good proxy of how much total output each variety offers in a region but also are capable of distinguishing varieties with respect to their adaptability levels. In other words, variance can be a misleading measure of adaptability.

In addition, it is shown in the Discussion section that degree of specificity can be used along with yield potential to measure gross revenue of a seed variety in a straightforward fashion.

This study assumes that farmers use previous year's information to select their canola variety each year. Therefore, lagged degree of specificity of each variety is used as an explanatory variable. A negative sign for this variable is expected to confirm proposition 2.[27]

In order to explore the importance of this new variable, absolute values of the degrees of specificities of different varieties are used in the regression model. However, regression analysis is also performed using relative values of degree of specificity. Procedures for calculation of relative degrees of specificity and regression results are presented in Appendix E.

Yield potential: A variety's yield is thought to have a key role in farmers' adoption decisions. Relative yield has been repeatedly used in seed adoption models such as those of Barkley and Porter (1996), Covey (2012), Dahl et al. (1999), and Gambrell (2004). The theoretical model of this study, on the other hand, recognizes *yield potential* to be one of the most important determinants of a variety's adoption. Also, as mentioned earlier, measures of yield potential (i.e. intercept or yield at the top yielding location) and degree of specificity (i.e. slope or the degree by which a variety's yield drops as area expands) work together to provide a proxy of how much total output each variety offers in a region. Therefore, this study uses yield potential instead of actual yield in order to test the propositions from the theoretical model.

It is also assumed that farmers use the yield potential information from the previous crop year to select their canola variety each year. Therefore, the regression analyses use lagged values of yield potential and relative yield potential instead of current values.

In order to explore the importance of this new variable absolute values of the yield potential are used in the regression model. Nevertheless, regression analysis is also performed using relative yield potential levels. Procedures for calculation of relative Yield Potential and regression results are presented in Appendix E.

Varieties' age: Many studies have recognized the length of time that a variety has been in the market to be an important determinant of the variety's market share (Covey, 2012; Dahl et al., 1999; Gambrell, 2004). More importantly, age of a variety is an important determinant of which

[27] Note that variety trial reports were not published in 2010 for Saskatchewan. It is assumed that in 2011 Saskatchewan farmers looked at the 2009 trial results.

stage of its life cycle the variety is at. Following the previous studies (Covey, 2012; Dahl et al., 1999; Gambrell, 2004) a polynomial of the third degree is used to capture the effect of age on a variety's life cycle.

There are a number of explanatory variables used in the previous studies that are not fitted in this study's set of independent variables. These variables include number of available varieties, dummies for producers of seed varieties, and seed varieties' prices. There have not been many variations in the number of available varieties in the study period so this variable is not used in the regression models. The variety fixed effect dummies can capture the effect of dummies for producers of seed varieties. As a result, the attempt to include dummy variables for important seed producers including Bayer, Monsanto, Pioneer, and Dow resulted in perfect multicollinearity. Nevertheless, effect of these variables on the dependent variable is estimated in a panel model with no cross-section fixed effects. Results of the estimations, which are presented in Appendix F, indicate that the dummy for Bayer has a positive and statistically significant sign.

As for seed varieties price, the theoretical framework presented in chapter 2 endogenizes the effect of seed prices on market share in exogenous variables. As shown in equation 10 of chapter 2, variety prices are a function of exogenous variables including yield potential levels and degree of specificity. Equation 11 in chapter 2 shows that equilibrium market share for each variety is a function of the same set of exogenous variables. As such, it is redundant to include the variety seed prices variable in a regression model that estimates market shares of seed varieties and already includes yield potential levels and degree of specificity as explanatory variables. More importantly, in the seed industry market share of a variety may affect its price (e.g. a successful variety may be priced higher). In such a case including seed prices in the set of explanatory variables introduces endogeneity.

Effect of the degree of specificity on length of product cycles is another interesting issue that has not been explored in this study. It is not possible to use the interaction of the *degree of specificity* and *variety's age* as an explanatory variable. This is because in each year the variable *variety's age* represents how many months a variety has been in the market for up to the start of the crop season of that year. Therefore, the two variables are completely independent. In order to explore the effect of degree of specificity on the length of product cycles one needs to regress the total number of years that varieties have been in the market on the degrees of specificity and other exogenous variables. For this purpose only those varieties that have completed their life cycles can be used. Also, for each variety there will be only one observation. To do such an analysis even the Manitoba dataset with 42 varieties is reduced in size to only 22 available observations. This sample size is not large enough to include all the relevant explanatory variables in the regression model. Moreover, one needs to use the average of the variety's degrees of specificity over their life cycles. This makes the interpretation of the results difficult.

4.4.3. Descriptive Statics

The Saskatchewan data set includes years 2007 to 2012. The 17 varieties (cross-sections) with at least two years of data are used from the Variety Performance Trial Report. The dataset has 102 potential observations. However, a trial report was not issued in 2010. It is assumed that Saskatchewan farmers used the information in 2009 Trial Reports for the 2011 crop year. Also, there is no data for some varieties in the 2011 and 2012 Variety Performance Trial Reports. After adjustments for the missing observations and lags the estimations are run as unbalanced panel with 72 observations.

The Manitoba dataset is for the 2004-2013 period with 42 varieties (cross-sections). Therefore, this dataset has 420 potential observations. After adjustments for only one missing observation and lags the estimations are run as unbalanced panel with 377 observations.

Descriptive statics of the variables used in the regression model are presented in Table 4.4. Average yield potential levels are higher in Saskatchewan as they are the trial report results, whereas yield potential levels in Manitoba are realized farm level yield levels. Similarly, average degree of specificity levels are higher in Saskatchewan as Saskatchewan data in limited to test locations. Average variety age increases from 6 months to 51 months in Saskatchewan in the study period. This variable ranges between 24 and 42 months in Manitoba. Area ranges from 110000 acres to 152000 acres in Saskatchewan. In Manitoba, this variable ranges between 120000 and 192000 acres.

Table 4. 4. Descriptive Statistics of the Main Variables.

Variables	Year	SK		MB	
		Mean	Standard Deviation	Mean	Standard Deviation
Yield Potential (bushels/acre)	2004	-	-	45.60	5.34
	2005	-	-	45.06	4.71
	2006	-	-	44.33	2.91
	2007	80.40	7.28	36.94	2.71
	2008	106.84	6.68	50.29	2.67
	2009	93.65	19.49	51.86	3.13
	2010	95.51	19.38	49.65	4.30
	2011	93.33	4.49	40.89	3.28
	2012	71.64	5.70	37.27	1.70
	2013			54.85	3.29
Area (acre)	2004	-	-	163484	80558
	2005	-	-	148294	96277
	2006	-	-	120070	134184
	2007	-	-	157330	170368
	2008	121258	152072	181484	123143
	2009	152006	204937	160727	213612
	2010	110659	187371	169306	244987
	2011	137490	219054	137388	223642
	2012	130063	261172	192182	254549
	2013	-	-	161979	166001
Variety's Age (month)	2004	-	-	28	18
	2005	-	-	37	18
	2006	-	-	42	22
	2007	6	14	33	18
	2008	21	21	39	22
	2009	29	20	34	24
	2010	32	24	34	22
	2011	41	26	32	25
	2012	51	26	24	17
	2013	-	-	29	16
Degree of specificity	2004	-	-	0.41	0.14
	2005	-	-	0.71	0.30
	2006	-	-	0.56	0.30
	2007	1.68	0.14	0.44	0.31
	2008	2.96	0.19	0.44	0.38
	2009	2.25	0.36	0.47	0.17
	2010	2.26	0.43	0.82	0.38
	2011	2.17	0.13	0.88	0.52
	2012	1.89	0.25	0.53	0.34
	2013	-	-	0.64	0.41

Source: Prairie Canola Variety Trials (2007-2009), Canola Performance Trials (2011-12, Manitoba Agricultural Services Corporation, Saskatchewan Crop Insurance Corporation, Canola Council of Canada, and author's calculations.

4.4.4. Estimation results

Estimation results are reported in Table 4.5. The model is estimated using Panel Estimated Generalized Least Square (EGLS) with cross-section weights for varieties. Differential effect of varieties on market shares creates heteroskedasticity. This issue is resolved using the EGLS method developed by Roy (2002) and a White cross-section standard errors and covariance matrix. [28]

The regression model is set up such that it allows for a variety's age to affect the variety's market share. This is common in the literature. The purpose is to find the shape of the product cycles. However, one may argue that a higher (lower) market share may result in an increase (decrease) in a variety's age as successful varieties may be kept in the market longer than unsuccessful varieties. This could potentially result in an endogeneity problem. However, the length of the time a variety is in the market is at least to some extent determined by the seed producer, independent of the success of the variety. That is, when a variety is introduced the seed producer keeps the variety keeps the variety in the market for a number of years, regardless of the variety's success. Also, as shown in Chapter 3, length of the product cycles and market shares are both determined by yield potential and degree of specificity. Therefore, it is more likely that length of the product cycles is determined by yield potential and degree of specificity rather than market shares. Nevertheless, it is still possible that in the case of exceptionally successful varieties such as InVigor 5440 really high market share has influenced the seed producers' decision and, thus, caused a lengthening of the product cycle. However, in the datasets that are used in this study the only varieties with exceptionally long product cycles are 1841 with a seven-year life cycle and 5440, which is still in the market. Therefore, it is unlikely that the variable *variety's age* causes endogeneity in the regression model.

The panel regressions for both Manitoba and Saskatchewan offer a much higher explanatory power compared to the pooled regressions presented in Appendix D and also compared to those of Barkley and Porter (1996) (80 percent), Covey (2012) (31 percent), Dahl et al. (1999) (49 percent), and Gambrell (2004) (81 percent). As shown in Table 4.5, the independent variables in

[28] For more information about EGLS and other methods of dealing with heteroskedasticity in panel models please see Baltagi (2005, p 81-82).

the panel regression models with variety fixed effects explain 91 and 89 percent of the variations in market share of canola seed varieties in Manitoba and Saskatchewan, respectively.

The panel regressions also provide plausible signs and high significance level for the regressors. All the independent variables in both regression models have plausible signs. Also, all of the explanatory variables except T^3 in the Saskatchewan model are statistically significant at 0.1 percent or 1 percent significance level.

Number of months a variety has been in the market is another important determinant of a variety's adoption curve. Each variety goes through both adoption and disadoption phases implying a hill-shaped adoption curve. The literature suggests a polynomial of the third degree for this variable (Barkley and Porter, 1996; Covey, 2012; Dahl et al.,1999; Gambrell, 2004). As shown in Table 4.5, for Saskatchewan the linear and the quadratic terms of this variable are statistically significant with positive and negative signs, respectively. The cubic term, however, is estimated to be insignificant in this study. This is not unexpected considering the shape of canola seed varieties' life cycles in Saskatchewan and short time series (2007 to 2012) in the Saskatchewan dataset.[29] This indicates a concave or hill-shaped adoption curve, which means a variety's market share has an increasing trend upon entrance but after a certain point it starts to fall. That is consistent with theory and literature on adoption curves. For Manitoba, the linear, the quadratic, and the cubic terms are significant at 0.1 percent level and have plausible signs. Considering the length of the time series in the Manitoba dataset (from 2004 to 2013) a polynomial of the third degree is justifiable. Interestingly, the magnitudes of the parameters on the linear, the quadratic, and the cubic terms are very close for Manitoba and Saskatchewan.

As stated in proposition 4, as a variety becomes more specific its market share decreases. The negative sign for Lag Mu for both Manitoba and Saskatchewan in Table 4.5 confirms the validity of proposition 4. Magnitude of the parameter estimated for this variable is -0.0358 for Manitoba and -0.0086 for Saskatchewan. The difference in the magnitude of the parameter for the two provinces could be attributed to the fact that degree of specificity for Manitoba is estimated using actual yield data while for Saskatchewan the yield data is obtained from Variety Trial Reports.

[29] For example, adoption curve of InVigor 5440 presented in Figure 4.5 resembles a polynomial of the second degree rather than a third degree.

This implies that farmers are likely to give more weight to actual yield information than information presented in Variety Trial Reports when making adoption decisions. The Lag Mu parameter for Manitoba means that 1 unit increase in degree of specificity of a variety decreases its market share by 3.6 percent.

Table 4. 5. Estimation results for Manitoba and Saskatchewan.

Province	Manitoba		Saskatchewan	
Dependent Variable:	Market share (%)		Market share (%)	
Estimation Method:	Panel (EGLS)		Panel (EGLS)	
Independent Variables	Coefficient	Standard Error	Coefficient	Standard Error
Constant	0.0078	0.0006***	0.0448	0.0011***
T	0.0038	0.0002***	0.0035	0.0005***
T^2	-0.0001	0.00001***	-0.0001	0.00002***
T^3	0.0000005	0.0000001***	0.0000003	0.0000002
Lag Mu	-0.0358	0.0129***	-0.0086	0.0024***
Lag YP	0.0009	0.0003***	0.0003	0.0001**
R-squared	0.83		0.89	
Adjusted R-squared	0.80		0.85	
F-Statistic	35.75***		19.52***	
Number of Cross-Sections:	42		17	
Number of Periods:	9		5	
Observations after adjustment:	377		72	

Source: Author's estimation.
Note: Asterisks denote significance at the10% (*), 5%(**), and 1%(***) levels.

Farmers are likely to look at yield potential of a variety when deciding which varieties of canola to grow. As shown in Table 4.5, lag of yield potential (Lag YP) is highly significant with a positive sign for both Manitoba and Saskatchewan models. Similar to the degree of specificity, however, magnitude of the parameter on this variable is larger for Manitoba than Saskatchewan. Similar to the parameters of degree of specificity explained above, this could be attributed to the fact that yield potential for Manitoba is estimated using actual yield data while for Saskatchewan the yield data is obtained from trial reports, implying that farmers' adoption decisions are likely to be more influenced by actual yield information than information presented in the trial reports.

The estimated parameters for Lag YP for Manitoba suggests that 1 bushel increase in a variety's yield potential per acre results in 0.09 percent increase in its market share. For

Saskatchewan, 1 bushel increase in a variety's reported yield potential per acre results in 0.03 percent increase in its market share.

Fixed Effects Vector Decomposition (FEDV) is reported in Table 4.6. These time invariant fixed or individual effects represent the effect of variety characteristics that are not included in the set of explanatory variables.

As shown in Table 4.6, the fixed effects vary from -7.2 percent to 20.5 percent in Saskatchewan and from -1.9 to 14.8 percent in Manitoba. This highlights the importance of heterogeneity of varieties in the canola seed industry. Also, some of the successful varieties such as 5440, 5020, and 5030 have very high fixed effects compared to other varieties in both provinces. This stresses the role of variety characteristics that are not included in the set of explanatory variables in market share of these varieties. Such characteristics may include oil profile, lodging quality, and the technology intrinsic to each category of seed.

The t-test results presented in the bottom part of Table 4.6 reveal that Liberty Link varieties with InVigor technology such as 5440, 5020, and 5030 have significantly higher fixed effects than Roundup Ready varieties in Manitoba and Saskatchewan. This provides more insight into the success of the varieties with InVigor technology. Further discussion on why some varieties have been more successful than others is provided in the next section.

Table 4. 6. Fixed Effect Vector Decomposition for Variety Effects on Market Shares.

Province	Manitoba				Saskatchewan	
Dependent Variable:	Market share (%)				Market share (%)	
Estimation Method:	Panel (EGLS)				Panel (EGLS)	
Seed Technology	Variety	Effect	Variety	Effect	Variety	Effect
Liberty Link(LL)	5440	0.148	L120	-0.012	5440	0.198
	5020	0.056	L154	-0.009	5020	0.205
	5030	0.062	L159	-0.008	5030	0.156
	8440	-0.002	5070	0.049	8440	0.006
	5770	-0.002	5108	-0.009	5770	-0.051
	L130	0.019	1145	-0.012	L130	-0.015
	L150	0.039	2573	-0.007	L150	0.009
	9590	-0.014	2663	-0.008		
Roundup Ready(RR)	9553	-0.019	V1030	-0.011	9553	-0.040
	45H28	-0.014	V1037	-0.015	45H28	-0.026
	1012	0.012	v2045	-0.010	4414	-0.072
	6060	-0.015	45H21	-0.002	997RR	-0.067
	71-45	-0.008	45H25	-0.012	6040	-0.051
	72-55	-0.014	45H26	-0.016	45H73	-0.038
	72-65	-0.014	45H29	-0.015	43 E 01	-0.063
	73-45	-0.018	34-55	-0.002	D3151	-0.063
	73-65	-0.008	34-65	-0.017		
	73-75	-0.005	9550	-0.015		
	1841	-0.012	NX4 105	-0.019		
Clearfield(CF)	2012CL	-0.011	46H75 (ST)	-0.012	5525	-0.065
	NEX 845CL	-0.008			5535	-0.060
Averages	**Manitoba**			**Saskatchewan**		
	LL	**RR**	**CF**	**LL**	**RR**	**CF**
	-0.008	-0.012	-0.010	0.072	-0.053	-0.063
T-Test Probability	**LL-RR**	0.021**		**LL-RR**	0.023**	
	LL-CF	0.281		**LL-CF**	0.017**	
	RR-CF	0.243		**RR-CF**	0.159	

Source: Author's estimation.
Note: Asterisks denote significance at the10% (*), 5%(**), and 1%(***) levels.

4.5. Discussion

The theoretical model presented in Chapter 2 determines yield potential and degree of specificity of seed varieties have an important role in adoption pattern. These findings are proven algebraically in Chapter 2 and via numerical simulations in Chapter 3. This chapter empirically tested the effect of yield potential and degree of specificity on market shares of canola seed varieties in Manitoba and Saskatchewan. Estimations show that higher yield potential results in higher market share and higher degree of specificity results in lower market share for Canadian canola seed varieties.

These findings reveal at least two interesting facts about the industry. First, looking at the combination of yield potential and degree of specificity of canola seed varieties, it is now clear why some varieties such as InVigor 5440 are more successful than other varieties. Second, seed industries' recent attempts to introduce bundled traits can be attributed to lower degree of specificity which results in higher market share for varieties with bundled traits.

An examination of InVigor 5440 provides further empirical evidence on the importance of yield potential and degree of specificity in success of a variety. InVigor 5440 was released in 2007 and has been one of the most successful varieties ever since. Table 4.7 and Figure 4.5 show the acreage of the top canola seed varieties in Saskatchewan. As shown in the figure and the graph below, InVigor 5440 has significantly higher acreage compared to other top varieties. This variety has been very successful in Manitoba as well. This raises the question as to why InVigor 5440 is more successful than other canola varieties.

Table 4. 7. Area under Cultivation and Release Year of Main Canola Varieties in Saskatchewan 2008-2012.

Variety	Release year	Area under cultivation in Saskatchewan (acres)					
		2008	2009	2010	2011	2012	**Total**
5020 INVIGOR	2003	444,318	249,017	116,731	41,641	5,914	857,621
5030 INVIGOR	2003	255,266	174,638	81,631	68,391	18,238	598,164
5440 INVIGOR	2007	196,302	708,076	747,316	882,899	537,337	3,071,930
8440 INVIGOR	2007	119,407	192,487	202,130	135,744	13,969	663,737
9553	2008	1,625	88,342	116,093	132,076	37,248	375,384
L130	2010				239,465	541,241	780,706
L150	2010				339,703	889,087	1,228,790

Source: Saskatchewan Crop Insurance Corporation.

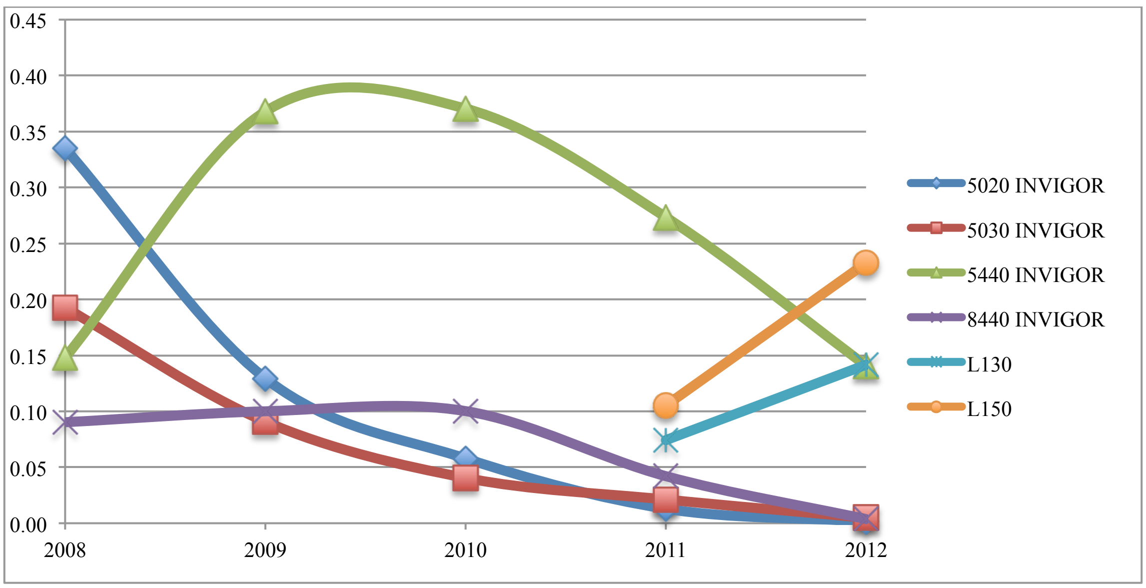

Figure 4. 5. Market Shares (%) of Main Canola Varieties in Saskatchewan 2008-2012.

Source: Saskatchewan Crop Insurance Corporation.

Success of InVigor 5440, to a great extent, can be attributed to its high yield potential and low degree of specificity. As shown in Equation 4 of Chapter 2, gross revenue from variety *i* is a function of its yield potential and degree of specificity as follows:

(4.3) $$Gross\ revenue\ of\ variety\ i = P\int_0^{X_i}(\hat{y}_i - \mu_i X_i)dX$$

where P is output price, $\hat{y}_i$, μ_i, and X_i are yield potential, degree of specificity, and area of variety i , respectively. Assuming $P = 1$ and $X_i = 1$ for $i = 1, \dots, n$ we have:

(4.4) *Gross revenue of variety i*= $\hat{y}_i - \frac{\mu_i}{2}$

Using this simple equation gross revenue of all canola varieties is calculated for 2007-2012. Table 4.8 shows Saskatchewan's top-three canola seed varieties for 2007-2012 in terms of their gross revenue calculated using equation 4.4. As shown in Table 4.8, InVigor 5440 has the highest gross revenue in 3 out of 5 years. In two out of five years 5440 is the second-best variety in terms of gross revenue. Comparing 5440 with 5770 and other canola varieties shows other varieties do not offer such consistently high gross revenues as 5440. Precisely, InVigor 5440 offers consistently high gross revenue under various weather and location effects. This reveals why 5440 has been more successful than other canola seed varieties in terms of market share. Consistently high yield potential and low degree of specificity of 5440 under various weather and location effects that results in high gross revenue draws farmers' demand.

Table 4. 8. Top Canola Varieties in Saskatchewan, 2007-2012.

Rank	Top Varieties				
	2007	2008	2009	2011	2012
First	5440(86.97)*	5440(113.34)	5770(108.73)	5440(95.87)	L150(76.36)
Second	5030(86.95)	8440(111.33)	5440(107.21)	L150(95.55)	5440(74.23)
Third	8440(81.24)	5030(110.56)	6040(103.89)	L130(92.82)	L130(72.95)

Note: *Numbers in the parentheses show average gross revenue ($/acre) calculated using equation 4.4.
Source: Author's calculation.

Nevertheless, it is worth noting that yield potential and degree of specificity cannot solely explain consistently high market shares. As mentioned before, there are observable and unobservable characteristics intrinsic to each variety that differentiate it from other varieties. These characteristics have an important role in each variety's gross revenue and market share. As shown in Table 4.6, successful varieties such as 5440, 5020, and 5030 also have very high fixed or time invariant effects compared to other varieties. For example, the fixed effect for 5440 suggests that on average characteristics intrinsic to this variety that are not included in the regression models, improve its average market share by 19.8 percent in Saskatchewan and 14.8 percent in Manitoba compared to the average of all the existing varieties, *ceteris paribus*.

4.6. Conclusion

Chapter 2 introduced a new theoretical model that explains the incentives to create new characteristics for new production inputs. Some properties of the model were shown in propositions and their algebraic proof. These propositions were further investigated through numerical simulations in chapter 3. The current chapter uses data from the Canadian canola industry to empirically test the propositions discussed in chapter 2. Specifically, this chapter provides empirical evidence on the effect of yield potential and degree of specificity on demand and price of seed varieties. In addition, this chapter provides empirical evidence as to why it is important to incorporate both seed and location characteristics when constructing a demand model for the seed industry.

Exploring the information from Canola Performance Trial Reports and Prairie Canola Variety Trials Test Results reveals that variations in yield levels of different varieties at different locations in different years can be attributed to variety, location, and weather (year) effects. It is shown through UNIANOVA that effect of weather on variety yield, to a great extent, occurs through locations. This further stresses the importance of incorporating both variety and location effects when constructing a demand model for a seed industry.

Using a panel model with variety fixed effects to capture the observable and unobservable seed characteristics that are not included in the set of explanatory variables is one of the contributions of this study to the literature on adoption of seed varieties. Another contribution of this study is to test the effect of yield potential and degree of specificity on market share of seed varieties. Results of the fixed effects panel regressions confirm proposition 2; as a variety becomes more specific its market share decreases. It is also shown that degree of specificity is a good measure of adaptability for seed varieties as it provides high explanatory power in the regression models and also can be used to make direct economic interpretation since it is easily translatable to measures of gross revenue. It is also shown that higher yield potential levels result in proportionately higher adoption rates. Moreover, the role of observable and unobservable seed characteristics that are not included in the set of explanatory variables is not negligible. These empirical results further stress the role of degree of specificity, yield potential, and other observable and unobservable characteristics such as the technology embodied in each type of seed in adoption of new and existing seed varieties.

These findings reveal at least two interesting facts about the industry. First, looking at the combination of yield potential and degree of specificity of canola seed varieties, it is now clear why some varieties such as InVigor 5440 are more successful than other varieties. InVigor 5440 offers consistently high gross revenue under various weather and location effects. This reveals why 5440 has been more successful than other canola seed varieties in terms of market share. Consistently high yield potential and low degree of specificity of 5440 under various weather and location effects, that result in high gross revenue, draws farmers' demand. Second, seed industries' recent attempts to introduce bundled traits can be attributed to lower degree of specificity which results in higher market share for varieties with bundled traits.

This study does not test the effect of yield potential and degree of specificity on seed prices. However, since both equilibrium price and market share equations in the theoretical model are obtained from the same profit maximization problem, estimation results from the market share regression model in this chapter can be generalized to argue that higher yield potential levels and higher degrees of specificity result in higher prices. Nevertheless, an empirical estimation of the effect of yield potential and degree of specificity on seed prices is suggested for future studies. This will provide more insight into the relative importance of different variables in seed pricing.

Appendix 4.A: Area of Canola Seed Varieties in Saskatchewan 2008-2012.

Table 4.A1. Area of Canola Seed Varieties in Saskatchewan 2008-2012.

	Area (acre)				
Variety	**2008**	**2009**	**2010**	**2011**	**2012**
1818	26,004	36,202	32,080	30,751	6,180
1918				6,008	10,222
1990 CANTERRA					30,289
1970				13,715	23,835
3151 D		18,393	50,837	55,750	11,497
3153 D					45,498
34-65	45,320	47,818	28,987	16,494	8,708
43 E 01		3,474	5,941	16,612	8,180
4414 RR	16,482	6,810	12,409	12,577	5,501
45H28	4,559	183,896	171,884	49,722	10,857
45H29			43,840	295,612	255,610
45H31					56,716
45H73	37,797	30,669	26,943	18,970	15,746
45H75					9,602
45S52				22,646	81,545
45S53					8,259
46A76	23,088	21,479	9,736	11,065	10,327
46H75					15,025
46S53					17,428
500 VT				89,508	200,507
5020 INVIGOR	444,318	249,017	116,731	41,641	5,914
5030 INVIGOR	255,266	174,638	81,631	68,391	18,238
5440 INVIGOR	196,302	708,076	747,316	882,899	537,337
5525 CL			15,455	36,732	25,466
5535 CL					10,023
5770 INVIGOR			92,618	139,695	56,785
6020					7,510
6040			6,228	16,323	12,610
6060				29,182	102,755
72-65		9,588	104,302	159,661	75,578
73-15 RR					9,113
73-45			4,610	141,728	237,411
73-55			3,583	39,032	24,584
73-65			2,775	26,452	6,440
73-75 RR					75,033
8440 INVIGOR	119,407	192,487	202,130	135,744	13,969
94H04					8,976
9553	1,625	88,342	116,093	132,076	37,248
9557S			2,686	10,736	5,956
9559 PROVEN VR					52,148
9560 CL					19,039
9590	140,388	137,067	124,828	42,304	10,435
997 RR	15,562	16,263	13,664	13,533	11,376
BARRIER VT				42,172	26,975
L120					87,285
L130				239,465	541,241
L150				339,703	889,087
L154					20,397
L159					22,383
REMARKABLE VT				53,035	36,789
TOTAL	**1,326,118**	**1,924,219**	**2,017,307**	**3,229,934**	**3,819,633**

Source: Saskatchewan Crop Insurance Corporation.

Appendix 4.B: Descriptive Statics

Table 4.B1. Number of Varieties and Trials across the Prairies, 2007- 2012.

Year	Total Number of Varieties	Number of Trials
2007	47	33
2008	40	27
2009	37	32
2010	Data Unavailable	Data Unavailable
2011	25	23
2012	24	23

Source: Prairie Canola Variety Trials (2007-2009), Canola Performance Trials (2011-12).

Table 4.B2. Number of Years, Varieties, and Potential Observations in Manitoba and Saskatchewan Datasets.

	Saskatchewan	Manitoba
Years	2007-2012	2004-2013
Varieties with Consistent Data	17	42
Number of Potential Observations	102	420

Source: Prairie Canola Variety Trials (2007-2009), Canola Performance Trials (2011-12), Manitoba Agricultural Services Corporation, and author's calculations.

Appendix 4.C: Poolability test

Greene (2012, p363) proposes the following F-test for poolability a data. Under the null hypothesis constant terms for all the cross-sections are equal and pooled least squares is the preferred regression model. The test statistic is as follows:

$$F(n-1, nT-n-K) = \frac{(R^2_{LSDV} - R^2_{Pooled})/(n-1)}{(1-R^2_{LSDV})/(nT-n-K)}$$

where R^2_{LSDV} is the R-squared from the panel regression with dummies for fixed effects, R^2_{Pooled} is the R-squared from the pooled regression, n is the number of cross-sections, T is the number years for each cross-section, and K is the number of explanatory variables not including the dummies in the panel regression.

Using the R-squared measures from the panel regressions reported in Table 4.4 and the pooled regressions presented in Table 4.D1 in Appendix 4.D, the F ratios for the two provinces are calculated as follows:

Saskatchewan: $F(16{,}62) = \frac{(0.89-0.23)/(17-1)}{(1-0.89)/(17\times 5-17-6)} = 23.25$

Manitoba: $F(41{,}330) = \frac{(0.83-0.47)/(42-1)}{(1-0.83)/(9\times 42-42-6)} = 18.94$

The critical value for $F(16{,}62, \alpha = 0.05)$ is 1.81 suggesting that the null hypothesis is rejected for Saskatchewan model. Similarly, for Manitoba, the critical value for $F(41{,}330, \alpha = 0.05)$ is 1.43 rejecting the null hypothesis. Therefore, the panel model is preferred to the pooled model in both provinces. It is worth noting that the large F ratio is mainly attributable to the large gap between the explanatory power of the panel regression and the pooled regression models suggesting that heterogeneity of cross-sections (varieties) plays a key role in explaining the within and between variations of canola seed varieties' adoption.

Appendix 4.D: Pooled Regression Results

Following table shows the results of the pooled regression models. This is for the purpose of comparison with Fixed Effects Panel models presented in Table 4.4. Pooled regressions provide much lower explanatory power compared to the Fixed Effects Panel models presented in Table 4.4 in both Saskatchewan and Manitoba. In addition, number of statistically significant variables and levels of significance seem to be higher in the Fixed Effects models compared to the pooled models.

Table 4.D1. Pooled Regression Results for Manitoba and Saskatchewan.

Province	Manitoba		Saskatchewan	
Dependent Variable:	Market share (%)		Market share (%)	
Estimation Method:	Pooled		Pooled	
Independent Variables	Coefficient	Standard Error (White)	Coefficient	Standard Error (White)
Constant	0.0001	0.0009	0.0054	0.0071
T	0.0042	0.0007***	-0.0011	0.0015
T^2	-0.00009	0.00003***	0.00008	0.0000006
T^3	0.0000005	0.0000002**	-0.0000008	0.0000005
Lag Mu	-0.089	0.013***	-0.0538	0.0217*
Lag YP	0.002	0.0003***	0.0019	0.0006**
R-squared	0.47		0.23	
Adjusted R-squared	0.46		0.18	
F-Statistic	65.83***		4.04**	
Number of Cross-Sections:	42		17	
Number of Periods:	9		5	
Observations after adjustment:	378		72	

Source: Author's estimation.
Note: Asterisks denote significance at the10% (*), 5%(**), and 1%(***) levels.

Appendix 4.E: Estimation Results with Relative Yield Potential

Table 4.E1 shows the results of the regression models when Relative Yield Potential is used instead of absolute values of Yield Potential as explanatory variables. Relative Yield Potential is the ratio of a variety's yield potential to the highest yield potential level in that year.

As shown in Table 4.E1, all the explanatory variables have plausible signs when relative values of Yield Potential is used. However, Relative Mu is not statistically significant for Saskatchewan. This may be due to small number of observations and limited variations in the Saskatchewan dataset. The estimation results indicate that when a variety becomes more specific relative to other varieties it obtains lower market share, *ceteris paribus*. Similarly, when a variety has higher yield potential relative to other varieties it receives higher market share, *ceteris paribus*.

Table 4.E1. Estimation Results with Relative Yield Potential.

Province	Manitoba		Saskatchewan	
Dependent Variable:	Market share (%)		Market share (%)	
Estimation Method:	Panel (EGLS)		Panel (EGLS)	
Independent Variables	Coefficient	Standard Error	Coefficient	Standard Error
Constant	0.009	0.0006***	0.0432	0.0009***
T	0.0029	0.0002***	0.0039	0.0003***
T^2	-0.00006	0.00001***	-0.0001	0.00002***
T^3	0.0000002	0.0000001	0.0000003	0.0000002*
Lag Relative Mu	-0.039	0.0103**	-0.0023	0.0015
Lag Relative YP	0.036	0.0086***	0.0152	0.0045***
R-squared	0.75		0.89	
Adjusted R-squared	0.72		0.84	
F-Statistic	21.85***		9.73***	
Number of Cross-Sections:	42		17	
Number of Periods:	9		5	
Observations after adjustment:	378		85	

Source: Author's estimation.
Note: Asterisks denote significance at the10% (*), 5%(**), and 1%(***) levels.

Appendix 4.F: Effect of Dummies for seed producers

Although the fixed effects in the estimated panel model capture the effect of seed producers' on the dependent variable, this appendix explores the effect of dummies for seed producers on market share of seed varieties. The model presented below is a panel regression similar to the one presented in Table 4.4 except for the fact that cross section fixed effect are dropped from the model in order to avoid perfect multicollinearity with seed producers' dummies.

Table 4.F1. Effect of Dummies for Seed Producers in a Panel Model with no Cross-Section Fixed Effects.

Province	Manitoba	
Dependent Variable:	Market share (%)	
Estimation Method:	Panel Least Squares	
Independent Variables	Coefficient	Standard Error
Constant	-0.0082	0.0020***
T	0.0043	0.0007***
T^2	-0.0001	0.00003***
T^3	0.0000004	0.0000002*
Lag Mu	0.0790	0.0132***
Lag YP	0.0018	0.00035***
Monsanto	0.0002	0.0019
Bayer	0.0240	0.0032***
Pioneer	-0.0032	0.0022
Dow	0.0052	0.0063
R-squared	0.50	
Adjusted R-squared	0.49	
F-Statistic	41.83***	
Number of Cross-Sections:	42	
Number of Periods:	9	
Observations after adjustment:	377	

Source: Author's estimation.
Note: Asterisks denote significance at the10% (*), 5%(**), and 1%(***) levels.

The model includes dummies for Monsanto, Bayer, Pioneer, and Dow. Other smaller seed companies including Agripogress, DL Seeds, and Cargill are categorized as "others" and dropped from the set of explanatory variables to avoid perfect multicollinearity.

The parameter estimated for Bayer is statistically significant and has a positive sign. This implies that farmers are more likely to buy their seed from Bayer than any other seed producer.

Appendix 4.G: Manitoba Dataset

Table 4.G.1. Manitoba Dataset: Degree of Specificity (mu).

	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
5440	0.00	0.00	0.00	0.00	0.23	0.22	0.39	0.23	0.19	0.23
5030	0.00	0.60	0.23	0.19	0.22	0.28	0.56	0.81	0.00	0.00
5020	0.42	0.62	0.20	0.24	0.23	0.37	0.85	0.00	0.00	0.00
5070	0.45	0.47	0.19	0.21	0.27	0.00	0.00	0.00	0.00	0.00
5770	0.00	0.00	0.00	0.00	0.00	0.00	0.49	0.42	0.50	0.00
8440	0.00	0.00	0.00	0.00	0.29	0.36	0.58	0.82	0.00	0.00
5108	0.00	0.00	0.00	0.39	0.00	0.00	0.00	0.00	0.00	0.00
9590	0.00	0.00	0.00	0.45	0.33	0.54	0.91	2.02	0.00	0.00
34-55	0.29	0.54	0.42	0.00	0.00	0.00	0.00	0.00	0.00	0.00
34-65	0.00	0.00	0.91	0.35	0.85	0.00	0.00	0.00	0.00	0.00
2573	0.28	0.76	0.75	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2663	0.36	0.95	0.69	0.00	0.00	0.00	0.00	0.00	0.00	0.00
35-85	0.68	1.40	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1841	0.00	0.00	0.76	0.57	0.56	0.79	0.00	0.00	0.00	0.00
9553	0.00	0.00	0.00	0.00	0.00	0.68	0.65	1.13	0.00	0.00
9550	0.51	0.52	0.60	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1145	0.00	0.00	0.00	0.00	0.00	0.00	1.21	0.00	0.85	0.00
L120	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.77	0.84
L130	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.36	0.20	0.24
L150	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.28	0.19	0.32
L154	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.66	0.31
L159	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.54
1012RR	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.24	0.32
71-45RR	0.00	0.00	1.03	0.20	0.19	0.29	1.27	0.00	0.00	0.00
73-45RR	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.77	0.47	0.85
72-55RR	0.00	0.00	0.00	0.00	0.00	0.36	0.58	0.00	0.00	0.00
6060RR	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.07	1.42
73-75RR	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.34	0.32
73-65RR	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.64	0.00	0.00
45H21	0.28	0.52	0.35	0.43	1.50	0.00	0.00	0.00	0.00	0.00
45H29	0.00	0.00	0.00	0.00	0.00	0.00	1.46	0.56	0.37	0.50
45H28	0.00	0.00	0.00	0.00	0.00	0.46	0.59	0.00	0.00	0.00
45H26	0.00	0.00	0.00	0.00	0.35	0.71	0.00	0.00	0.00	0.00
45H25	0.00	0.00	0.00	0.41	0.00	0.00	0.00	0.00	0.00	0.00
46H75 (ST)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.49
2012CL	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.09	0.31	0.72
NEX 845CL	0.00	0.00	0.00	1.34	0.28	0.44	0.00	0.00	0.00	0.00
72-65 (RT)	0.00	0.00	0.00	0.00	0.00	0.00	0.56	0.99	1.26	0.00
NX4 105 RR	0.00	0.00	0.00	0.00	0.00	0.59	0.62	1.19	0.00	0.00
V1037	0.00	0.00	0.00	0.00	0.00	0.49	1.55	0.00	0.00	0.00
V1030	0.00	0.00	0.00	0.45	0.00	0.00	0.00	0.00	0.00	0.00
V2045	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.83

Source: Manitoba Agricultural Services Corporation and author's calculations.

Table 4.G.2. Manitoba Dataset: Market share (%).

Variety	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
5440	0.00	0.00	0.00	0.00	0.10	0.37	0.40	0.45	0.22	0.23
5030	0.00	0.13	0.23	0.28	0.16	0.13	0.06	0.03	0.00	0.00
5020	0.10	0.17	0.24	0.22	0.20	0.09	0.03	0.00	0.00	0.00
5070	0.09	0.26	0.27	0.19	0.11	0.00	0.00	0.00	0.00	0.00
5770	0.00	0.00	0.00	0.00	0.00	0.00	0.11	0.10	0.03	0.00
8440	0.00	0.00	0.00	0.00	0.08	0.12	0.10	0.04	0.00	0.00
5108	0.00	0.00	0.00	0.05	0.00	0.00	0.00	0.00	0.00	0.00
9590	0.00	0.00	0.00	0.04	0.06	0.04	0.04	0.01	0.00	0.00
34-55	0.14	0.10	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00
34-65	0.00	0.00	0.03	0.03	0.02	0.00	0.00	0.00	0.00	0.00
2573	0.19	0.06	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2663	0.20	0.06	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00
35-85	0.07	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1841	0.00	0.00	0.03	0.03	0.03	0.01	0.00	0.00	0.00	0.00
9553	0.00	0.00	0.00	0.00	0.00	0.02	0.03	0.01	0.00	0.00
9550	0.04	0.04	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1145	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.00	0.02	0.00
L120	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.03
L130	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.07	0.15	0.19
L150	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.16	0.32	0.11
L154	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.05
L159	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.04
1012RR	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.09	0.17
71-45RR	0.00	0.00	0.02	0.07	0.11	0.06	0.01	0.00	0.00	0.00
73-45RR	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.02	0.01
72-55RR	0.00	0.00	0.00	0.00	0.00	0.04	0.04	0.00	0.00	0.00
6060RR	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.02
73-75RR	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.04	0.08
73-65RR	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.00
45H21	0.18	0.14	0.07	0.03	0.01	0.00	0.00	0.00	0.00	0.00
45H29	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.05	0.03	0.04
45H28	0.00	0.00	0.00	0.00	0.00	0.04	0.04	0.00	0.00	0.00
45H26	0.00	0.00	0.00	0.00	0.05	0.02	0.00	0.00	0.00	0.00
45H25	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.00
46H75 (ST)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01
2012CL	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.04	0.02
NEX 845CL	0.00	0.00	0.00	0.01	0.08	0.03	0.00	0.00	0.00	0.00
72-65 (RT)	0.00	0.00	0.00	0.00	0.00	0.00	0.06	0.02	0.01	0.00
NX4 105 RR	0.00	0.00	0.00	0.00	0.00	0.01	0.03	0.01	0.00	0.00
V1037	0.00	0.00	0.00	0.00	0.00	0.02	0.02	0.00	0.00	0.00
V1030	0.00	0.00	0.00	0.03	0.00	0.00	0.00	0.00	0.00	0.00
V2045	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01

Source: Manitoba Agricultural Services Corporation and author's calculations.

Table 4.G.3. Manitoba Dataset: Yield Potential (bushels/acre).

Variety	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
5440	0.00	0.00	0.00	0.00	53.80	55.26	52.35	40.05	37.52	57.86
5030	0.00	49.66	47.34	39.50	52.21	54.61	48.44	41.80	0.00	0.00
5020	52.09	48.18	46.70	38.61	50.84	54.26	51.54	0.00	0.00	0.00
5070	52.43	49.33	46.01	39.90	52.42	0.00	0.00	0.00	0.00	0.00
5770	0.00	0.00	0.00	0.00	0.00	0.00	53.91	41.51	36.79	0.00
8440	0.00	0.00	0.00	0.00	53.58	56.14	54.01	43.66	0.00	0.00
5108	0.00	0.00	0.00	33.53	0.00	0.00	0.00	0.00	0.00	0.00
9590	0.00	0.00	0.00	40.92	51.17	53.76	51.03	42.44	0.00	0.00
34-55	41.08	41.55	41.05	0.00	0.00	0.00	0.00	0.00	0.00	0.00
34-65	0.00	0.00	45.36	34.17	46.19	0.00	0.00	0.00	0.00	0.00
2573	47.56	48.00	42.17	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2663	47.11	47.51	44.39	0.00	0.00	0.00	0.00	0.00	0.00	0.00
35-85	43.86	42.92	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1841	0.00	0.00	46.46	38.01	48.62	47.66	0.00	0.00	0.00	0.00
9553	0.00	0.00	0.00	0.00	0.00	51.65	45.25	39.69	0.00	0.00
9550	36.74	35.46	38.16	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1145	0.00	0.00	0.00	0.00	0.00	0.00	56.21	0.00	38.12	0.00
L120	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	36.23	57.89
L130	0.00	0.00	0.00	0.00	0.00	0.00	0.00	41.40	37.82	56.31
L150	0.00	0.00	0.00	0.00	0.00	0.00	0.00	41.57	36.11	57.95
L154	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	39.39	56.94
L159	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	55.88
1012RR	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	38.98	53.82
71-45RR	0.00	0.00	46.90	35.81	46.72	49.32	43.16	0.00		0.00
73-45RR	0.00	0.00	0.00	0.00	0.00	0.00	0.00	41.67	36.30	49.54
72-55RR	0.00	0.00	0.00	0.00	0.00	52.28	44.36	0.00	0.00	0.00
6060RR	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	37.82	57.21
73-75RR	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	38.88	53.22
73-65RR	0.00	0.00	0.00	0.00	0.00	0.00	0.00	45.68	0.00	0.00
45H21	43.91	42.96	43.13	38.06	50.69	0.00	0.00	0.00	0.00	0.00
45H29	0.00	0.00	0.00	0.00	0.00	0.00	55.49	42.34	39.08	54.64
45H28	0.00	0.00	0.00	0.00	0.00	53.47	48.23	0.00	0.00	0.00
45H26	0.00	0.00	0.00	0.00	50.62	52.72	0.00	0.00	0.00	0.00
45H25	0.00	0.00	0.00	34.11	0.00	0.00	0.00	0.00	0.00	0.00
46H75	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	57.47
2012CL	0.00	0.00	0.00	0.00	0.00	0.00	0.00	31.38	35.56	51.25
NEX	0.00	0.00	0.00	37.67	46.62	47.67	0.00	0.00	0.00	0.00
72-65	0.00	0.00	0.00	0.00	0.00	0.00	48.98	41.39	33.22	0.00
NX4 105	0.00	0.00	0.00	0.00	0.00	51.38	48.22	37.83	0.00	0.00
V1037	0.00	0.00	0.00	0.00	0.00	45.93	43.63	0.00	0.00	0.00
V1030	0.00	0.00	0.00	33.04	0.00	0.00	0.00	0.00	0.00	0.00
V2045	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	47.92

Source: Manitoba Agricultural Services Corporation and author's calculations.

Table 4.G.4. Manitoba Dataset: Variety's Age (months).

Variety	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
5440	0	0	0	0	12	24	36	48	60	72
5030	0	19	31	43	55	67	79	91	0	0
5020	7	19	31	43	55	67	79	0	0	0
5070	7	19	31	43	55	0	0	0	0	0
5770	0	0	0	0	0	0	9	21	33	0
8440	0	0	0	0	12	24	36	48	0	0
5108	0	0	0	31	0	0	0	0	0	0
9590	0	0	0	11	23	35	47	59	0	0
34-55	47	59	71	0	0	0	0	0	0	0
34-65	0	0	12	24	36	0	0	0	0	0
2573	48	60	72	0	0	0	0	0	0	0
2663	47	59	71	0	0	0	0	0	0	0
35-85	27	39	0	0	0	0	0	0	0	0
1841	0	0	47	59	71	83	0	0	0	0
9553	0	0	0	0	0	12	24	36	0	0
9550	15	27	39	0	0	0	0	0	0	0
1145	0	0	0	0	0	0	9	0	33	0
L120	0	0	0	0	0	0	0	0	8	20
L130	0	0	0	0	0	0	0	7	19	31
L150	0	0	0	0	0	0	0	7	19	31
L154	0	0	0	0	0	0	0	0	6	18
L159	0	0	0	0	0	0	0	0	6	18
1012RR	0	0	0	0	0	0	0	0	2	14
71-45RR	0	0	10	22	34	46	58	0	0	0
73-45RR	0	0	0	0	0	0	0	13	25	37
72-55RR	0	0	0	0	0	12	24	0	0	0
6060RR	0	0	0	0	0	0	0	0	20	32
73-75RR	0	0	0	0	0	0	0	0	12	24
73-65RR	0	0	0	0	0	0	0	13	0	0
45H21	24	36	48	60	72	0	0	0	0	0
45H29	0	0	0	0	0	0	12	24	36	48
45H28	0	0	0	0	0	12	24	0	0	0
45H26	0	0	0	0	24	36	0	0	0	0
45H25	0	0	0	25	0	0	0	0	0	0
46H75 (ST)	0	0	0	0	0	0	0	0	0	25
2012CL	0	0	0	0	0	0	0	2	14	26
NEX 845CL	0	0	0	1	13	25	0	0	0	0
72-65 (RT)	0	0	0	0	0	0	24	36	48	0
NX4 105 RR	0	0	0	0	0	12	24	36	0	0
V1037	0	0	0	0	0	18	30	0	0	0
V1030	0	0	0	30	0	0	0	0	0	0
V2045	0	0	0	0	0	0	0	0	0	10

Source: Canadian Food Inspection Agency and author's calculations.

Table 4.G.5. Manitoba Dataset: Seed Producers.

Variety	Producer
5440	Bayer
5030	Bayer
5020	Bayer
5070	Bayer
5770	Bayer
8440	Bayer
5108	Bayer
9590	Bayer
34-55	Monsanto
34-65	Bayer
2573	Monsanto
2663	Agriprogress
35-85	Pioneer
1841	Unknown
9553	Bayer
9550	Bayer
1145	Bayer
L120	Bayer
L130	Bayer
L150	Bayer
L154	Bayer
L159	Bayer
1012RR	Dow
71-45RR	Monsanto
73-45RR	Monsanto
72-55RR	Monsanto
6060RR	DL
73-75RR	Monsanto
73-65RR	Monsanto
45H21	Pioneer
45H29	Pioneer
45H28	Pioneer
45H26	Pioneer
45H25	Pioneer
46H75	Pioneer
2012CL	Dow
NEX	Dow
72-65 (RT)	Unknown
NX4 105	Dow
V1037	Cargill
V1030	Cargill
V2045	Cargill

Source: Canadian Food Inspection Agency.

Appendix 4.H: Saskatchewan Dataset

Table 4.H.1. Saskatchewan Dataset: Market Share (%).

Variety	2008	2009	2010	2011	2012
3151 D	0.00	0.01	0.03	0.02	0.00
43 E 01	0.00	0.00	0.00	0.01	0.00
4414 RR	0.01	0.00	0.01	0.00	0.00
45H28	0.00	0.10	0.09	0.02	0.00
45H73	0.03	0.02	0.01	0.01	0.00
5020 INVIGOR	0.34	0.13	0.06	0.01	0.00
5030 INVIGOR	0.19	0.09	0.04	0.02	0.00
5440 INVIGOR	0.15	0.37	0.37	0.27	0.14
5525 CL	0.00	0.00	0.01	0.01	0.01
5535 CL	0.00	0.00	0.00	0.00	0.00
5770 INVIGOR	0.00	0.00	0.05	0.04	0.01
6040	0.00	0.00	0.00	0.01	0.00
8440 INVIGOR	0.09	0.10	0.10	0.04	0.00
9553	0.00	0.05	0.06	0.04	0.01
997 RR	0.01	0.01	0.01	0.00	0.00
L130	0.00	0.00	0.00	0.07	0.14
L150	0.00	0.00	0.00	0.11	0.23

Source: Saskatchewan Crop Insurance Corporation and author's calculations.

Table 4.H.2. Saskatchewan Dataset: Degree of Specificity (mu).

Variety	2007	2008	2009	2010	2011	2012
3151 D	0.00	3.07	2.14	2.14		
43 E 01	0.00	0.00	1.57	1.57		
4414 RR	-1.48	2.88	2.88	0.00		
45H28	0.00	3.34	2.01	2.01		
45H73	-1.55	2.69	2.20	2.20		
5020 INVIGOR	-1.73	2.98	2.16	2.16		
5030 INVIGOR	-1.83	2.98	2.31	2.31		
5440 INVIGOR	-1.81	3.07	2.40	2.40	2.28	1.99
5525 CL	0.00	0.00	2.07	2.07	1.97	1.69
5535 CL	0.00	0.00	0.00	0.00	1.97	1.57
5770 INVIGOR	0.00	0.00	2.45	2.45	2.08	
6040	0.00	0.00	3.42	3.42		
8440 INVIGOR	-1.69	3.06	2.31	2.31		
9553	0.00	2.87	2.02	2.02		
997 RR	0.00	2.78	2.78	0.00		
L130	0.00	0.00	0.00	0.00	2.24	2.02
L150	0.00	0.00	0.00	0.00	2.26	2.18

Source: Canola Council of Canada and author's calculations.

Table 4.H.3. Saskatchewan Dataset: Yield Potential (bushels/acre).

Variety	2007	2008	2009	2010	2011	2012
3151 D	0.00	105.63	95.86	95.86		
43 E 01	0.00	0.00	36.38	36.38		
4414 RR	69.27	99.11	99.11			
45H28	0.00	110.65	94.58	94.58		
45H73	75.31	101.52	96.30	96.30		
5020 INVIGOR	80.00	110.43	98.94	98.94		
5030 INVIGOR	87.87	112.05	104.81	104.81		
5440 INVIGOR	87.88	114.87	108.42	108.42	97.02	75.23
5525 CL	0.00	0.00	96.39	96.39	85.90	67.89
5535 CL	0.00	0.00	0.00	0.00	85.90	63.65
5770 INVIGOR	0.00	0.00	109.96	109.96	93.09	
6040	0.00	0.00	105.60	105.60		
8440 INVIGOR	82.09	112.87	103.13	103.13		
9553	0.00	103.24	95.78	95.78		
997 RR	0.00	96.80	96.80			
L130	0.00	0.00	0.00	0.00	93.94	73.96
L150	0.00	0.00	0.00	0.00	96.69	77.45

Source: Canola Council of Canada and author's calculations.

Table 4.H.4. Saskatchewan Dataset: Variety's Age (months).

Variety	2007	2008	2009	2010	2011	2012
3151 D	0	0	12	24	36	48
43 E 01	0	0	12	24	36	48
4414 RR	5	17	29	41	53	65
45H28	0	0	12	24	36	48
45H73	12	24	36	48	60	72
5020 INVIGOR	43	55	67	79	91	103
5030 INVIGOR	43	55	67	79	91	103
5440 INVIGOR	0	12	24	36	48	60
5525 CL	0	0	0	9	21	33
5535 CL	0	0	0	0	12	20
5770 INVIGOR	0	0	0	9	21	33
6040	0	0	0	0	6	18
8440 INVIGOR	0	12	24	36	48	60
9553	0	0	12	24	36	48
997 RR	5	17	29	41	53	65
L130	0	0	0	0	7	19
L150	0	0	0	0	7	19

Source: Canadian Food Inspection Agency and author's calculations.

Table 4.H.4. Saskatchewan Dataset: Seed Producers.

Variety	Producer
3151 D	Pioneer
43 E 01	Pioneer
4414 RR	DL
45H28	Pioneer
45H73	Pioneer
5020 INVIGOR	Bayer
5030 INVIGOR	Bayer
5440 INVIGOR	Bayer
5525 CL	DL
5535 CL	DL
5770 INVIGOR	Bayer
6040	DL
8440 INVIGOR	Bayer
9553	Pioneer
997 RR	Brett Young
L130	Bayer
L150	Bayer

Source: Canadian Food Inspection Agency.

Chapter 5: Conclusion

5.1. Introduction

The present study attempts to fill a gap in the literature by exploring the physical and economic forces that influence the dynamic path of hybrid seed pricing for a broad acre crop over time. Of the physical and economic forces influencing the dynamic path of hybrid development, the sequential and cumulative nature of crop development is particularly discussed.

This study provides a better understanding of the development of a seed industry that is characterized by the hybrid system and sequential and cumulative innovation. Specifically, the canola hybrid seed industry in Canada is studied. Given the high rates of return to research, and the scope of the potential costs and benefits for producers, economic research in this area could have profound impact on producers and the economic future of the region.

Policies put in place to strengthen IPRs over the next few years will shape the future of the grain industry for many decades to come. A more complete understanding of how an industry, characterized by sequential and cumulative innovation, can develop with hybrid systems or stronger intellectual property rights will inform better policy choices and investment decisions. This study will have particularly important implications for industries that are considering stronger intellectual property rights inside and outside Canada.

Chapter 1 of this dissertation presents the background, literature and research objectives. Chapter 2 introduces a theoretical model that explains the incentives to create new characteristics for crop varieties while incorporating sequential innovation, multiple characteristics, and differentiated buyers for the varieties. Chapter 3 performs numerical simulations to provide more insight into the findings of the theoretical model. Chapter 4 empirically tests some of the propositions presented in Chapter 2. The goal of the current chapter is to present a conclusion of the findings of this study.

The remainder of this chapter is organized as follows. First, conclusions from the important findings of the study are presented. Then, policy implications and potential approaches for future research are discussed.

5.2. Conclusion of the Study

The model presented in Chapter 2 makes a significant contribution to the "product variety" literature. While Chamberlinian models are confined to one representative consumer and location models are not very helpful in analysis of more than two characteristics, the model developed in Chapter 2 incorporates differentiated buyers and multiple characteristics. What distinguishes this model from similar models is the focus on farm input characteristics rather than characteristics in consumer products. Although the model may have similarities to monopolistic competition models of analyzing product variety (i.e. location, Chamberlinian and hybrid models), it has a different perspective in that it uses the concept of "characteristics" introduced by Lancaster (1966) to explain the innovation process for production inputs that embody new characteristics.

This model provides important insight into the incentives for innovation through the creation of new characteristics. It shows that even with a yield potential that is lower than its rivals, a seed variety still has a chance to profitably enter the market by introducing a new characteristic. Schumpeter's *temporary market power* can be derived from new characteristics embodied in old products.

Proposition 1 of the theoretical model shows that similar to final consumer products, farm input buyers obtain unbounded gains from an increase in number of available products. The model finds yield potential and degree of specificity to be very important determinants of seed varieties prices, market shares, and profit levels. Also, degree of specificity and rate of yield potential growth seem to influence number of equilibrium varieties and length of product cycles. Proposition 2 shows that as varieties become more specific, they will each obtain a lower market share and number of equilibrium varieties increases. Proposition 3 reveals that more specific varieties can be prices higher.

Propositions 4 and 5 show that a higher rate of yield potential improvement results in higher prices and larger market shares for the superior varieties and lower prices and market shares for older and lower quality varieties. This, in turn, results in a faster decrease in both price and market share. Faster decrease in prices and market shares implies shorter but steeper disadoption cycles. This means, in more progressive industries (i.e. industries with higher rates of quality improvement) product cycles are shorter. This, in turn, results in smaller equilibrium number of firms. That is, more progressive industries are likely to have a smaller equilibrium number of firms, *ceteris paribus*. However, rate of innovation, itself, may be endogenous and determined by the other exogenous factors. This issue is discussed in Chapter 3.

Chapter 3 builds on the results derived from the theoretical model to consider other aspects of sequential innovation. In Chapter 3, numerical simulations are performed to further investigate the validity of the propositions presented in Chapter 2. This chapter provides some important and novel insights into dynamic aspects of the model, such as product cycles.

Chapter 3 endogenizes rate of yield potential growth as a function of firms' initial investment. This chapter identifies 3 exogenous determinants of optimal investment and the consequent rate of yield potential growth. These 3 factors are breeders' investment productivity, degree of specificity of varieties, and fixed overhead or maintenance cost of keeping a variety in the market. These factors are important determinant of optimal investment level, number of varieties, prices, market shares at the equilibrium steady states, length of product cycles and consolidation.

Breeders' investment productivity also represents economies of size as more productive breeders can gain higher yield growth rates per investment dollar. Greater investment productivity results in lower optimal investment levels as with higher investment productivity levels firms do not need to invest as much to attain similar or higher rates of yield growth. Greater investment productivity also results in fewer varieties in the market, shorter product cycles, higher prices, higher profit levels, lower optimal investment, and higher consolidation.

Degree of specificity of varieties also represents degree of consumers' heterogeneity. More specific varieties imply more varieties in the market. However, more specific varieties can be priced higher. Simulation results also show that with more specific varieties firms' optimal investment level increases.

An increase in fixed overhead or maintenance cost of keeping a variety in the market results in shorter yet flatter product cycles. Higher fixed maintenance cost also results in a more consolidated market with fewer equilibrium varieties that are priced higher and gain higher profit levels. This also results in lower optimal investment.

The results of Chapter 3 provide very interesting insights into the impact of differentiation on equilibrium conditions. While the common belief is that differentiation can increase a firm's profit, the numerical simulations show that this relationship is not as straightforward. It is shown that increased differentiation, if followed by the rivals, will certainly result in increased profit as long as it is not followed by entry of new firms. However, if increased differentiation creates enough space in the market for a new entrant, then entry of a new rival will increase competition and may result in a decrease in the incumbents' profit.

Chapter 4 uses data from Canadian canola industry to empirically test some of the propositions discussed in chapter 2. Specifically, this chapter provides empirical evidence on the effect of yield potential and degree of specificity on demand and price of seed varieties.

Results indicate that variations in yield levels of different varieties at different locations in different years can be attributed to variety, location, and weather effects. It is shown that effect of weather on variety yield, to a great extent, occurs through locations. This further stresses the importance of incorporating both variety and location effects when constructing a demand model for a seed industry.

An important contribution of this study to the literature on adoption of seed varieties is using a panel model with variety fixed effects to capture the observable and unobservable seed characteristics that are not included in the set of explanatory variables. Previous studies try to capture the observables in the set of explanatory variables included in a pooled regression model.

Another contribution of this study is to test the effect of yield potential and degree of specificity on market share of seed varieties. Results confirm that as a variety becomes more specific its market share decreases. It is also shown that degree of specificity is a proper measure of adaptability for seed varieties as it provides high explanatory power in the regression models and also can be used to make direct economic interpretation since it is easily translatable to measures of gross revenue.

It is also shown that higher yield potential levels result in proportionately higher adoption rates. Moreover, the role of observable and unobservable seed characteristics that are not included in the set of explanatory variables is not negligible. These empirical results further stress the role of degree of specificity, yield potential, and other observable and unobservable characteristics such as the technology embodied in each type of seed in adoption of new and existing seed varieties.

Findings of Chapter 4 reveal two interesting facts about the industry. First, looking at the combination of yield potential and degree of specificity of canola seed varieties, it is now clear why some varieties such as InVigor 5440 are more successful than other varieties. InVigor 5440 offers consistently high gross revenue under various weather and location effects. Consistently high yield potential and low degree of specificity of 5440 under various weather and location effects, that result in high gross revenue, draws farmers' demand. Second, seed industries' recent attempts to introduce bundled traits can be attributed to lower degree of specificity which results in higher market share for varieties with bundled traits.

5.3. Policy Implications

Impact of Rate of Innovation on Industry Structure: Although rate of innovation is very likely an endogenous factor determined by other exogenous variables such as cost structure, it is important to understand the implications of a higher or lower rate of innovation on industry structure. The theoretical model introduced in this study shows that a higher rate of yield potential improvement results in a faster decrease in prices and market shares of older varieties in the market. This, in turn, results in shorter life cycles for the products and smaller equilibrium number of firms, *ceteris paribus*. This implies that more progressive industries (i.e. industries with higher rates of innovation) are likely to have fewer products at equilibrium. This is simply because in a highly progressive industry older products become unattractive faster than they would in industries with lower rates of innovation. This is also evident in the smartphone industry where very few highly progressive firms have dominated the market with a few products.

Therefore, if investment productivity, cost structure, degree of heterogeneity of consumers, and other exogenous factors allow the firms in an industry to have a high rate of innovation, then one can expect a highly consolidated market with high prices for products that are replaced with newer ones faster than they would in a less progressive industry.

Degree of specificity and trait bundling: Findings of this dissertation reveal that degree of specificity of a seed variety is an important determinant of its success. Varieties that are not very specific can be used to obtain consistent yield levels in various locations and weather conditions. This is extremely important for farmers, given the great impact of unpredictable weather conditions in agriculture. Farmers reduce risk by allocating a percentage of their land to a variety that performs reasonably well in various locations and weather conditions even if that variety does not have the highest yield potential. A perfect example is canola seed variety InVigor 5440.

Seed companies' recent attempts to produce varieties with bundled traits can be explained from the perspective of degree of specificity. Varieties with bundled traits are less specific (i.e. more adaptable).

Differentiation: While the common belief is that differentiation can increase a firm's profit, the numerical simulations reveal one of the interesting complexities of this relationship. It is shown that if increased differentiation creates enough space in the market for a new entrant, then entry of a new rival will increase competition and may result in a decrease in the incumbents' profit. On the other hand, as it is shown in Proposition 1, increase in number of varieties improves farmers' total surplus. Therefore, firms' attempt to obtain higher profit levels through increased differentiation will work if increased differentiation does not result in entry. However, if increased differentiation results in entry, then firms' may or may not obtain higher profit levels depending on the change in relative prices and market shares while buyers will certainly benefit from increased variety.

5.4. Future Research

This study, if not first, is certainly one of the first studies to introduce a theoretical model that incorporates differentiated buyers, multiple characteristics, and sequential innovation for farm inputs. Similar to most original theoretical models, the focus has been on keeping the model simple enough to remain tractable and transparent. As a result, some potentially interesting theoretical and empirical aspects have been unexplored. The purpose of this section is to identify some of the research areas that may result in interesting findings.

Multiproduct firms: The model presented in Chapter 2 does not consider multiproduct firms. It is assumed that each firm releases only one product in the market. The model focuses on the effect of new differentiated entrants on competition. Therefore, despite the potentially insightful results, the multiproduct case is beyond the scope of this study. Nevertheless, it would be very interesting for future studies to explore pricing decisions of multiproduct firms in a setup that incorporates multiple characteristic and sequential innovation.

Investment decisions: Although this dissertation endogenizes rate of yield potential growth as a function of initial investment via numerical simulations, it may be interesting to incorporate investment decisions in the theoretical model as well.

Differentiation: This study attempts to provide a better understanding of the development path of an industry characterized by sequential innovation. It is shown that degree of specificity of seed varieties is an important determinant of number equilibrium products and consolidation level. In the theoretical model and numerical simulations presented in this study it is assumed that degree of specificity of products is exogenous. However, at least in long run, degree of specificity can be a choice variable for profit-maximizing firms. Firms can choose the level of differentiation of their products in order to maximize their profit. Future studies may incorporate this choice variable into the theoretical model and numerical simulations. This will add another stage and a great deal of complexity to the game, as firms now will have two choice variables. However, research in this area may identify the exogenous factors that determine optimal differentiation. This will have very important implications for industry structures and number of firms in different industries.

Land constraint: The existence of outside land would increase the overall elasticity of demand for new characteristics as introduction of new varieties with new characteristics may encourage farmers to use the marginal land that has not been allocated to that crop previously. However, this is unlikely to be quantitatively important except in the case of drastic innovation, where a new variety significantly expands total crop area. At least from a theoretical perspective, it would be interesting for future studies to incorporate the effect of acreage expansion in case of drastic innovation. It is worth noting that allowing for acreage expansion or reduction will help incorporate the effect of an "outside good" as well.

Effect of degree of specificity and yield potential on prices: This study was not able to find data on canola seed varieties' prices to test the effect of degree of specificity and yield potential on seed prices. Although these variables are shown to significantly impact market shares, it would be insightful to estimate the effect of yield potential and degree of specificity on seed prices. Comparison of the relative magnitude of the estimated parameters may intrigue interesting and important research questions.

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